VOL. 103, PARTS 1 & 2 28 FEBRUARY, 1979

TRANSACTIONS OF THE

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

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TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA INC.

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PARTS 7 & 8, 30 NOVEMBER

NEW SPECIES AND A CATALOGUE OF STIGMODERA (CASTIARINA) (COLEOPTERA: BUPRESTIDAE)

BY *S. BARKER*

Summary

A key to the sub-genera of Stigmodera Eschscholtz is given. The location of LaPorte & Gory types of Stigmodera (Castiarina) in the Hope Department of Etymology, University of Oxford is discussed. Seven species previously considered members of the sub-genus Castiarina are transferred: alternata Lumholtz, maculiventris MacLeay, nickerli Obenberger, praeterita Carter, punctatostriata Saunders and secularis Thomson to the sub-genus Themognatha; rudis Carter to Stigmodera (sensu stricto). Replacement names are given for three primary homonyms: auripennis Barker for aurifera Carter 1922 (a primary homonym of S. aurifera) LaPorte & Gory 1837); planata Carter, an available synonym for auricollis Thomson 1857 (a primary homonym of S. auricollis LaPorte & Gory 1837); magnificollis Barker for magnifica Blackburn (a primary homonym of S. magnifica LaPorte & Gory 1837). A replacement name is given for one secondary homonym: hoblerae Carter for mastersi MacLeay 1872, a secondary homonym of S. mastersi (MacLeay) 1872, subsequently transferred to Stigmodera from Neocuris.

NEW SPECIES AND A CATALOGUE OF *STIGMODERA (CASTIARINA)* (COLEOPTERA: BUPRESTIDAE)

by S. BARKER*

Summary

BARKER, S. (1979) New species and a catalogue of *Stigmodera (Castiarina)* (Coleoptera: Buprestidae). *Trans. R. Soc. S. Aust.* **103**(1), 1-23, 28 February, 1979.

A key to the sub-genera of *Stigmodera* Eschscholtz is given. The location of LaPorte & Gory types of *Stigmodera (Castiarina)* in the Hope Department of Entomology, University of Oxford is discussed. Seven species previously considered members of the sub-genus *Castiarina* are transferred: *alternata* Lumholtz, *maculiventris* MacLeay, *nickerli* Obenberger, *praeterita* Carter, *punctatostriata* Saunders and *secularis* Thomson to the sub-genus *Themognatha; rudis* Carter to *Stigmodera (sensu stricto).* Replacement names are given for three primary homonyms: *auripennis* Barker for *aurifera* Carter 1922 (a primary homonym of *S. aurifera* LaPorte & Gory 1837); *planata* Carter, an available synonym for *auricollis* Thomson 1857 (a primary homonym of *S. auricollis* LaPorte & Gory 1837); *magnificollis* Barker for *magnifica* Blackburn (a primary homonym of *S. magnifica* LaPorte & Gory 1837). A replacement name is given for one secondary homonym: *hoblerae* Carter for *mastersi* MacLeay 1872, a secondary homonym of *S. mastersi* (MacLeay) 1872, subsequently transferred to *Stigmodera* from *Neocuris.*

Seventeen new species of the sub-genus *Castiarina (bakeri, borealis, brooksi, carnabyi, crockerae, georgiana, macmillani, metallica, nigriceps, occidentalis, ovata, planipes, richardsi, subacuticeps, uptoni, verdiceps, walfordi)* are described and illustrated. Male genitalia of 15 of them are illustrated.

A synonymy is given for the sub-genus *Castiarina* and distribution is indicated by State or country. It is considered that there are 308 valid species in the sub-genus.

Introduction

Stigmodera Eschscholtz 1829, with more than 400 described species, is the largest genus within the Australian Buprestidae. In *Stigmodera* the mouthparts are produced downwards to form a short rostrum, the pores on the antennae concentrated into fovea on the toothed segments, the labrum long, coloured like the clypeus, the posterior edge of the pronotum sinuate, the frons not narrowed between the antennal cavities (Britton, 1970). There are three recognised sub-genera: *Stigmodera (sensu stricto)* Eschscholtz 1829, type species *macularia* (Donovan) 1805, with a total of eight species; *Themognatha* Solier 1833, type species *variabilis* (Donovan) 1805, with over 100 species; *Castiarina* LaPorte & Gory 1837, type species *pertyi* LaPorte & Gory 1837, with over 300 species.

Key to sub-genera of Stigmodera (modified from Carter, 1929)

1. Elytra hollowed out with large foveoles; medium to large size . . . . . *Stigmodera (sensu stricto)*
   Elytra striate or punctate-striate; sometimes with costae 2

2. Usually with tarsal hooks lobed and toothed at base; hair on dorsal surface of head; oval or round scutellum; medium to large size . . . . . *Themognatha*
   Tarsal hooks always simple; never with hair on dorsal surface of head; scutellum heart-shaped or shield-shaped never round or oval; small to medium size . . . . . *Castiarina*

Théry (1937) subdivided *Themognatha* but here I consider it a single sub-genus. Despite its size the genus has never been revised in the modern sense, although Carter (1916, 1929, 1931a, 1931b) published a key to species, a check-list and a key to the species

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of the sub-genus *Castiarina*. Here I present descriptions of 17 new species and a catalogue of species. The main revision of *Castiarina* will be published when illustrations of all species are completed.

LaPorte & Gory types in the collection of the Hope Department of Entomology

The pamphlet on Australian Buprestidae, privately circulated by the Rev. F. W. Hope in 1836 was cited by LaPorte & Gory (1837) in their monograph, but was subsequently declared unavailable for the purposes of nomenclature by the International Commission on Zoological Nomenclature (1948), thus legalising a decision made 80 years previously by leading British entomologists of the day (*Proc. ent. Soc. Lond.* 5: cix-cx, 1868). The only objection was lodged by Dr J. Obenberger of Prague. Later Obenberger (1955) had his personal copy of the Hope pamphlet photographically reproduced in a paper, to make it 'available to all scientific investigators'. Although the Hope pamphlet remains unavailable for the purposes of nomenclature, the Hope "types" are extant. I have found that the types of some of the LaPorte & Gory species are not held in the collection of the Paris Museum. The species in question were attributed to Hope by LaPorte & Gory (1837), and under the relevant names the phrase "Du cabinet de M. Hope" appears in brackets. Authenticated specimens of all of these species are held in the Type collection of the Hope Department of Entomology, University of Oxford. The LaPorte & Gory names and the Hope Department of Entomology numbers are:

S. semicincta 982; *S. amabilis* 983; *S. andersoni* 959; *S. cruenta* 970; *S. bicingulata* 963; *S. bicincta* 962; *S. jospilota* 967; *S. sexspilota* 968; *S. sieboldi* 969; *S. apicalis* 965.

I conclude that the above specimens are the types of the respective LaPorte & Gory species.

Species herein removed from the sub-genus Castiarina

The following species are transferred to the sub-genus *Themognatha*.

S. secularis Thomson
  = *bifasciata* Saunders (secondary homonym of *bifasciata* (Hope))
  = *bizonata* Obenberger
  = *eburnea* Carter
S. alternata Lumholtz*
S. punctatostriata Saunders*
S. maculiventris MacLeay*
  = *rubricauda* Saunders
  = *praecellens* Kerremans
  = *notaticollis* Carter
S. praeterita Carter*
S. nickerli Obenberger*
  = *strandi* Obenberger

S. rudis Carter is a lycid mimic. The type is unique but has damaged legs and antennae. It belongs either in *Stigmodera* (*sensu stricto*) or in a new monotypic sub-genus.

Homonyms and replacement names

S. aurifera Carter 1922, is a primary homonym of *S. aurifera* LaPorte & Gory 1837, p. 49 and I replace it with *S. auripennis* Barker. *S. auricollis* Thomson 1857 is a primary homonym of *S. auricollis* LaPorte & Gory 1837, p. 64. An available synonym, *S. planata* Carter 1916, becomes the valid name. *S. magnifica* Blackburn 1896 is a primary homonym of *S. magnifica* LaPorte & Gory 1837, p. 57 and I replace it with *S. magnificollis* Barker. *S. mastersi* MacLeay 1872, p. 245 is a secondary homonym of *S. mastersi* (MacLeay) 1872, p. 241 subsequently transferred to *Stigmodera* from *Neocuris*. *S. hoblerae* Carter 1922, an available synonym of this species, becomes the valid name.

The abbreviations used in the text for museum and private collections are as follows:

EA	Mr E. E. Adams, Edungalba, Qld.
GA	Mr G. Anderson, Alexandra, Vic.
ANIC	Australian National Insect Collection, C.S.I.R.O., Canberra.
JB	Mr J. A. G. Brooks, Cairns, Qld.
KC	Mr & Mrs K. Carnaby, Wilga, W. Aust.
AWH	Mr A. Walford-Huggins, Cairns, Qld.
BPBM	Bernice P. Bishop Museum, Honolulu.
BM	British Museum (Natural History), London.
JM	Mr J. Macqueen, Toowoomba, Qld.
NMV	National Museum of Victoria, Melbourne.
PI	Department of Primary Industry, Darwin.
RS	Mr R. I. Storey, Mareeba, Qld.
SAM	South Australian Museum, Adelaide.
WADA	Western Australian Department of Agriculture, South Perth.
WAM	Western Australian Museum, Perth.

* The basal teeth of the tarsal hooks are very small or absent.

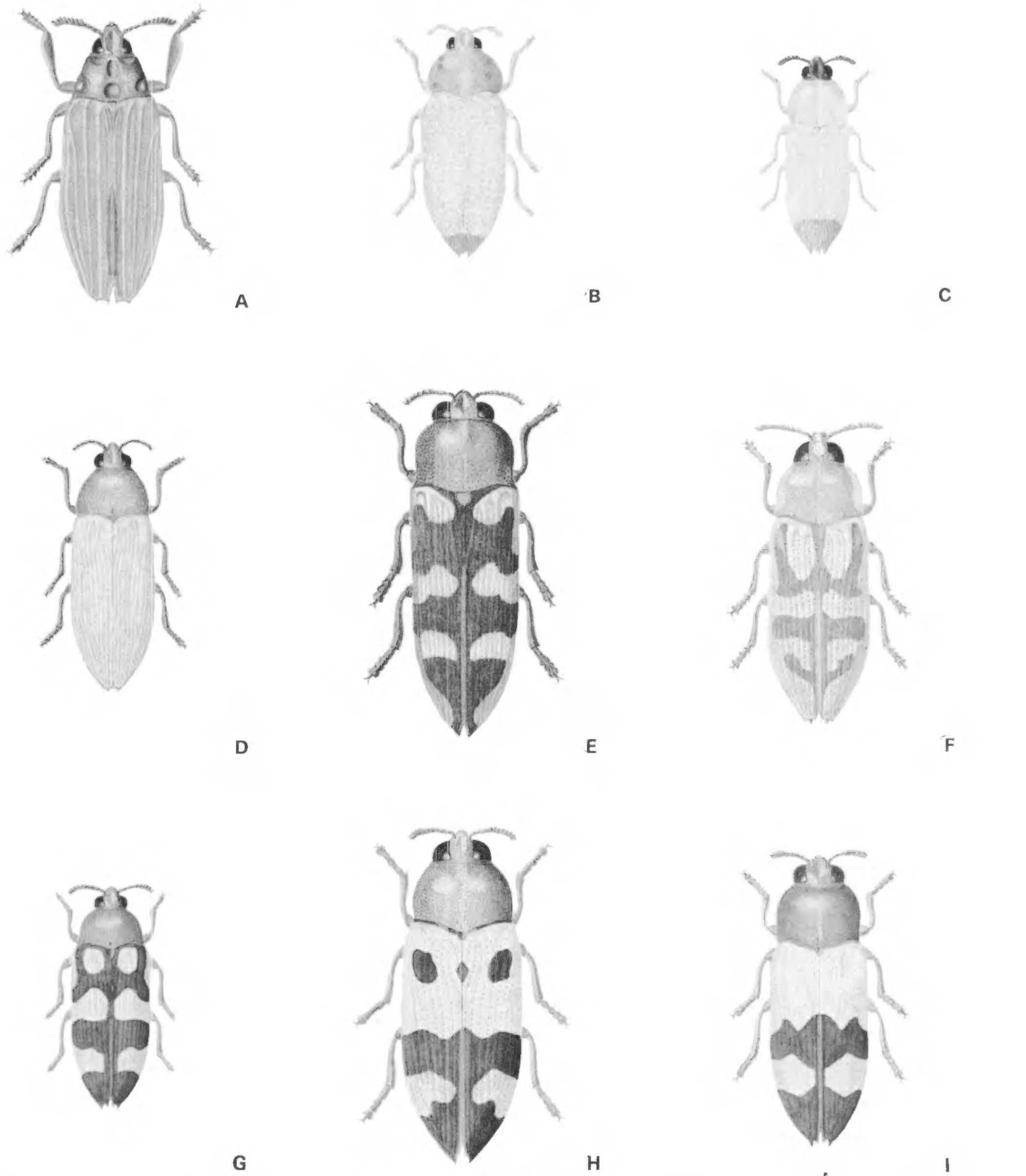

Fig. 1. x 3 natural size. A. *Stigmodera planipes sp.* nov. B. *Stigmodera crockerae* sp. nov. C. *Stigmodera nigriceps* sp. nov. D. *Stigmodera metallica* sp. nov. E. *Stigmodera bakeri* sp. nov. F. *Stigmodera richardsi* sp. nov. G. *Stigmodera subacuticeps* sp. nov. H. *Stigmodera georgiana* sp. nov. I. *Stigmodera verdiceps* sp. nov.

Stigmodera (Castiarina) planipes sp. nov.
FIGS 1A, 4A

Types: Holotype: ♂, Edungalba, Qld, 20.x. 1968, *E. E. Adams,* SAM I 21081. Allotype: ♀, Edungalba, Qld, 7.xi.1960, *E. E. Adams,* SAM I 21082. Paratypes: 1 ♀, Dalby, Qld, *Mrs F. H. Hobler,* SAM; 1 ♀, Armidale, N.S.W., *C. F. Deuquet,* SAM; 4 ♂ & 4 ♀, Millmerran, Qld, x.1945, *J. Macqueen,* JM & EA; 2 ♂ & 2 ♀, Edungalba, Qld, 8.x.1947, *E. E. Adams,* EA; 1 ♂, Edungalba, Qld, 20.x.1968, *E. E. Adams,* SAM; 1 ♂, 10 km n-west Edungalba, Qld, 1.xi.1975, *S. Barker,* SAM; 1 ♂, Edungalba, Qld, x.1976, *E. E. Adams,* SAM.

Colour: Head, pronotum, scutellum black with yellow reflections. Antennae, undersurface and legs black with blue reflections. Elytra red-brown with narrow black basal margin and

variable black edging to suture, wings black but not opaque. Hairs silver.

Shape and sculpture: Head evenly but shallowly punctured with deep median groove between eyes, glabrous with small elevated knob on inside of each antennal cavity, muzzle moderately elongate. Antennae serrate. Pronotum evenly and shallowly punctured, glabrous; circular fovea in centre at base facing upwards; small fovea in centre near apex facing upwards and forwards; small fovea on each side of anterior margin; irregular fovea on each side before middle; projecting forwards in middle of apical edge; base bisinuate; laterally tapered from base to apex. Scutellum shield-shaped, concave in middle, without punctures, glabrous. Elytra elongate; costate with 4 costae on each elytron, intervals closely punctured and round, costae smooth; laterally angled outwards from base, rounded at shoulder then slightly concave until after middle, then rounded and tapered to preapical area, then more sharply tapered to apex which is truncate; bispinose, both spines small, interval between slightly curved inwards. Undersurface with shallow punctures, larger on anterior part than on abdomen; edges of abdominal sclerites glabrous; sparsely haired; last abdominal segment truncate in both sexes; tibia of forelegs laterally compressed at apex and unusually wide. In lateral profile projecting in meso- and metasternal area, abdomen tapering to apex. Females broader than males.

Size: Males 12.2 ± 0.23 x 4.2 ± 0.07 mm (14). Females 13.2 ± 0.30 x 4.8 ± 0.09 mm (9).

Distribution: Queensland and New South Wales.

General remarks: Grouped with *S. latipes* Carter. Both species are lycid mimics and have inflated fore-tibia. Differs from *S. latipes* as it is smaller, sculpture on pronotum less pronounced, head and pronotum glabrous.

Specimens examined: Types; 3 ♂, no data, SAM.

Stigmodera (Castiarina) crockerae sp. nov.

FIGS 1B, 4B

Types: Holotype: ♂, Afghan Rocks, Balladonia Stn, W. Aust., on *Eucalyptus foecunda*, 2.ii.1975, *S. Barker*, SAM I 21083. Allotype: ♀, Afghan Rocks, Balladonia Stn, W. Aust., on *Eucalyptus foecunda* 2.iii.1975, *S. Barker*, SAM I 21084. Paratypes: 1 ♂ & 2 ♀, Afghan Rocks, Balladonia Stn, W. Aust., 1.iii.1975, *S. Barker*, SAM; 8 ♂ & 10 ♀, same data as holotype, SAM.

Colour: Head mottled red-brown, antennae testaceous. Pronotum mottled red-brown. Scutellum red-brown border, rest testaceous. Elytra yellow with testaceous spots, with narrow red-brown anterior margin and red-brown apex. Undersurface: anterior part mottled red-brown; coxae with 2 red-brown patches, remainder yellow with testaceous spots. Legs mostly yellow with testaceous spots; femora with red-brown stripe. Hairs silver.

Shape and sculpture: Head closely punctured with groove between eyes; muzzle short. Pronotum closely punctured; anterior margin straight, base bisinuate; laterally rounded from base and widest 1/3 from base, tapered to apex. Scutellum heart-shaped, closely punctured. Elytra punctate-striate, intervals flat at base, convex at apex; closely punctured surface, pitted and rough; laterally angled out from base, rounded at shoulder then slightly concave until after middle, round to apex which is bispinose; marginal spine larger than sutural spine, rounded and indented between; apices not diverging. Undersurface closely punctured and rough with few hairs, except in males which have patch of sensory bristles on either side of mid-line on meso- and metasternum; last abdominal segment truncate in male, rounded in female.

Size: Males 8.4 ± 0.20 x 3.0 ± 0.08 mm (18). Females 9.2 ± 0.16 x 3.4 ± 0.05 mm (14).

Distribution: Western Australia and South Australia.

General remarks: A cryptic species grouped with *S. testacea* Saunders. Differs from *S. testacea* in being larger, not costate, pronotum is inflated in middle. Named after Mrs A. E. Crocker of Balladonia Stn, Western Australia.

Specimens examined: W. Aust.: types; 3 ♂, Lake Grace, SAM; 3 ♂ & 1 ♀, Piawanning, 28.i.1951, *R. P. McMillan*, SAM; 1 ♂, 16 km south Borden, 27.ii.1956, SAM. S. Aust., 1 ♂, no data, SAM.

Stigmodera (Castiarina) nigriceps sp. nov.

FIGS 1C, 4C

Types: Holotype: ♂, 15 km east Einasleigh, Qld, 11.i.1970, *R. Storey & T. T. Marsh*, SAM I 21085. Allotype: ♀, 11 km west Mt Carbine, Qld, 21.xii.1977, *R. Storey & K. Halfpapp*, SAM I 21086. Paratypes: 5 ♂, 11 km west Mt Carbine, Qld, 21.xii.1977, *R. Storey & K. Halfpapp*, 3 SAM & 2 AWH; 1

♂, 11 km west Mt Carbine, Qld, 1.i.1978, *R. Storey*, RS; 1 ♂, 9 km NW Mt Molloy, Qld, 8.i.1978, *Nat & R. I. Storey*, RS; 1 ♀, Darwin, N.T., 27.x.1970, *T. Weir*, PI.

Colour: Head and antennae black. Pronotum, scutellum, undersurface and legs testaceous. Elytra testaceous with brown apical mark, reduced to two apical spots or entirely absent in some specimens, accessory post-medial spots on each elytron in some specimens. Hairs silver.

Shape and sculpture: Head closely punctured with median groove between eyes; muzzle short. Pronotum closely punctured, with small basal fovea projecting forwards as median impressed line, with basal notches on each side towards margin; anterior margin straight; basal margin bisinuate; laterally rounded from base to apex and widest in middle, dorso-ventrally flattened at sides, more so at base than at apex. Scutellum shield-shaped, concave in middle and with punctures. Elytra punctate-striate, intervals flat at base, convex at apex, with many punctures, surface uneven; laterally slightly angled out from base, rounded at shoulder then concave until after middle, rounded to apex which is bispinose; marginal spine larger than sutural spine, indented and rounded between; apices not diverging. Undersurface closely and shallowly punctured, hairs sparse except at anterior margin and with two rows of sensory bristles on either side of midline on the meso- and meta-sternal sclerites in males, absent in females. Last abdominal segment rounded in both sexes.

Size: Males 7.6 ± 0.16 x 2.7 ± 0.05 mm (8). Females 7.6 x 2.9 mm (2).

Distribution: Northern Territory and Queensland.

General remarks: Grouped with *S. testacea* Saunders and *S. crockerae* Barker. It differs from the other two species, being smaller and having a black head.

Specimens examined: Types only.

Stigmodera (Castiarina) metallica sp. nov.

FIGS 1D, 4D

Types: Holotype: ♂, Tallering Stn, 10 km north Pindar, W. Aust. on *Eucalyptus oldfieldi*, 27.xii.1975, *S. Barker*, SAM I 21087. Allotype: ♀, Tallering Stn, 10 km north Pindar, W. Aust. on *Eucalyptus oldfieldi*, 27.xii.1975, *S. Barker*, SAM I 21087. Paratypes: 1 ♂, same data as holotype, SAM; 2 ♂ & 2 ♀, Southern Cross, W. Aust., 12.i.1936, *H. W. Brown*, NMV; 2 ♂ & 1 ♀, Yellowdine, W. Aust., i.1939, *F. E. Wilson*, NMV; 1 ♂, Dedari, W. Aust., *H. W. Brown*, ANIC; 1 ♂, Marloo Stn, Wurarga, W. Aust., 1931–1941, *A. Goerling*, ANIC; 2 ♂ & 2 ♀, Lake Grace, W. Aust., 27.xii.1969, *K. & E. Carnaby*, KC; 1 ♂ & 1 ♀, Southern Cross, W. Aust., *H. W. Brown*, WAM; 3 ♂ & 1 ♀, Dedari, W. Aust., 15.i.1950, *A. M. Douglas*, WAM.

Colour: Head, antennae, pronotum, scutellum, undersurface and legs either all metallic green or all metallic copper, the two colours not sex linked. Elytra pale yellow, anterior margin same colour as rest of body.

Shape and sculpture: Head closely punctured, with broad groove between eyes; muzzle short. Pronotum closely punctured, with faint median glabrous line extending to middle from elongate basal fovea; anterior margin projecting forwards in middle; basal margin bisinuate; laterally rounded from base to apex, widest before middle then narrowed to apex. Scutellum heart-shaped and flat with few shallow punctures. Elytra punctate-striate, intervals flat and smooth at anterior end, convex at apex; laterally slightly angled out from base, rounded at shoulder then concave until after middle, then rounded and narrowed to apex which is bispinose; marginal spine larger than sutural spine, rounded and indented between; apices slightly diverging; apical margin finely serrate. Undersurface with close shallow punctures, moderately hairy. Last abdominal segment truncate in male, bilobed and pressed in, in female.

Size: Males 10.6 ± 0.17 x 3.5 ± 0.05 mm (14). Females 10.9 ± 0.31 x 3.7 ± 0.08 mm (8).

Distribution: Western Australia.

General remarks: Grouped with *S. pallidipennis* Blackburn, but differs from that species being smaller and narrower, apical margin subserrate, abdomen never testaceous.

Specimens examined: Types only.

Stigmodera (Castiarina) bakeri sp. nov.

FIGS 1E, 4E

Types: Holotype: ♂, Wialki, W. Aust., 18.ix.1957, *S. Barker*, SAM I 21089. Allotype: ♀, 88 km NE Wubin, W. Aust., 17.ix.1970, *S. Barker*, SAM I 21090. Paratypes: 8 ♂ & 2 ♀, 62 km NE Wubin, W. Aust., 29.ix.1972, *F. H. Uther Baker*, SAM; 6 ♂ & 3 ♀, 74 km SW Payne's Find, W. Aust., 17.ix.1972, *F. H. Uther Baker*, SAM; 1 ♂ & 1 ♀, 88 km NE

Wubin, W. Aust., 17.ix.1970, *S. Barker*, SAM; 1 ♂ & 1 ♀, Wialki, W. Aust., 18.ix.1957 & 21.ix.1970, *S. Barker*, SAM; 7 ♂ & 13 ♀, Marloo Stn, Wurarga, W. Aust., 1931–1941, *A. Goerling*, ANIC; 1 ♂ & 1 ♀, Wongan Hills, W. Aust., *H. W. Brown*, ANIC.

Colour: Head and antennae blue-green in male, bronze or green in female. Pronotum black in centre, blue-green at margins in male, margins bronze or green in females. Scutellum dark blue. Undersurface and legs blue. Elytra yellow with red margins, each elytron with following dark blue markings: thin band along basal margin; fascia before middle, expanded forwards at outer edge and backwards where it touches margin; a fascia after middle touching margin and exanded forwards in middle; spade-shaped preapical mark; fascia are connected down suture and to apex. Hairs silver.

Shape and sculpture: Head closely punctured, with median groove between eyes; muzzle short. Pronotum closely punctured, punctures at lateral margin larger than those in middle, with shallow, round depression at base of each side near margin, an elongate but shallow median impressed line projecting forwards from basal fovea to middle; apical margin projecting forwards in middle; basal margin bisinuate; laterally parallel-sided from base until after middle then abruptly rounded to apex. Scutellum shield-shaped and flat, without punctures, glabrous. Elytra punctate-striate, intervals flat near base, convex at apex; laterally angled out from base for short distance, rounded at shoulder then concave until after middle then rounded to apex; no apical spines, apices diverging. Undersurface with long hair, dense at anterior part, less dense on abdomen; last abdominal segment truncate and slightly indented in middle in males, deeply indented in middle and folded under in females.

Size: Males 13.2 ± 0.21 x 4.3 ± 0.07 mm (26). Females 14.7 ± 0.32 x 4.9 ± 0.12 mm (21).

Distribution: Western Australia.

General remarks: Grouped with *S. browni* Carter but differs in being a smaller species, is not bispinose and has a smooth apical margin. Named after Dr F. H. Uther Baker.

Specimens examined: Types only.

Stigmodera (Castiarina) richardsi sp. nov.
FIGS 1F, 4F

Types: Holotype: ♂, Coral Bay, W. Aust., 28.viii.1974, *K. & E. Carnaby*, SAM I 21091. Allotype: ♀, Coral Bay, W. Aust., 27.viii.1974, *K. & E. Carnaby*, ANIC. Paratypes: 2 ♂, Coral Bay, W. Aust., 28.viii.1974, *K. & E. Carnaby*, KC; 6 ♂ & 1 ♀, Coral Bay, W. Aust., 4.ix.1971, *K. T. Richards*, WADA; 2 ♂ & 1 ♀, 19 km north Coral Bay, W. Aust., 4.ix.1971, *K. T. Richards*, WADA; 3 ♂ & 1 ♀, 120 km south Exmouth, W. Aust., 4.ix.1971, *K. T. Richards*, WADA; 2 ♂ & 1 ♀, Coral Bay, W. Aust., 29.viii.1974, *K. & E. Carnaby*, ANIC; 1 ♂ & 1 ♀, Coral Bay, W. Aust., 27.viii.1974, *K. & E. Carnaby*, ANIC.

Colour: Head, antennae, mouthparts and legs green with yellow reflections, head with yellow frontal spot. Pronotum green with yellow reflections, yellow down lateral margins. Scutellum bright green. Elytra yellow with following bright green markings: vitta from each shoulder is connected to premedial fascia which does not reach margin; post-medial fascia concave to base; preapical spot on each elytron connected obliquely to suture, all connected down suture and reaching innermost two spines. Red marginal border present, thicker at apex than at base. Undersurface: edges of abdominal segments yellow; sutures green; hairs silver.

Shape and sculpture: Head closely punctured, flat between eyes, muzzle short. Pronotum closely punctured with small basal fovea in middle and basal notches on each side, closer to the margin than middle; projecting forwards in middle of anterior margin, basal margin barely bisinuate; laterally rounded from base to apex, widest 1/3 from base. Scutellum shield-shaped, flat with few punctures. Elytra punctate-striate, intervals convex at apex, flatter at base, punctured at shoulder and close to margins, not near suture; laterally angled outwards from base, rounded at shoulder then concave until after middle then rounded and narrowed to apex which is trispinose; inner and outer spines small, middle spine larger; apices slightly diverging. Undersurface with shallow punctures and few short hairs. Last abdominal segment truncate in male, indented and bilobed in female.

Size: Males 11.3 ± 0.24 x 4.1 ± 0.08 mm (17). Females 12.1 ± 0.26 x 4.5 ± 0.06 mm (6).

Distribution: Western Australia.

General remarks: Grouped with *S. flaviceps* Carter but differs from that species being trispinose and having bright green markings. Named after Mr K. T. Richards.

Specimens examined: Types only.

Stigmodera (Castiarina) subacuticeps sp. nov.

FIGS 1G, 4G

Types: Holotype: ♂, Badjaling, W. Aust., 30.ix.1970, *S. Barker*, SAM I 21092. Allotype: ♀, Badjaling, W. Aust., 30.ix.1970, *S. Barker*, SAM I 21093. Paratypes: 6 ♂ & 7 ♀, South Tammin Flora Reserve, W. Aust., 8.xi.1970, *S. Barker*, SAM; 3 ♂ & 1 ♀, Lake Grace, W. Aust., 1.xi.1970, *K. & E. Carnaby*, SAM; 1 ♀, Ajana, W. Aust., 16.ix.1958, *F. H. Uther Baker*, SAM; 1 ♂, Tallering Stn, Pindar, W. Aust., 7.ix.1976, *R. P. McMillan*, SAM; 1 ♂, 3 km south Maya, W. Aust., 3.xi.1968, *N. McFarland*, SAM; 2 ♂ & 3 ♀, Marloo Stn, Wurarga, W. Aust., 1931–1941, *A. Goerling*, ANIC.

Colour: Head and antennae black with blue reflections. Pronotum green with blue reflections or blue. Scutellum, undersurface and legs black with blue reflections. Hairs silver. Elytra yellow with following black markings all with blue reflections: anterior margin; premedial fascia with ends expanded into a vitta reaching anterior margin and posteriorly lateral margin, enclosing basal spot and elongate marginal mark; straight post-medial fascia touching margin; apical mark. All marks connected down suture.

Shape and sculpture: Head closely and shallowly punctured with median groove between eyes, muzzle short. Pronotum closely punctured with shallow elongate basal depression projecting forwards as impressed line from base to apex, more obvious at apex; with basal notch on each side, closer to margin than centre; apical margin straight, basal margin barely bisinuate; laterally flared out at base, pinched in then rounded and narrowed to apex. Scutellum heart-shaped and glabrous. Elytra punctate-striate, intervals convex, more so at apex and flatter at base with shallow punctures in basal area, smooth at apex; laterally angled out from base, rounded at shoulder, concave until after middle, rounded to apex which is bispinose; marginal spine larger than sutural, interval between rounded and indented; apices slightly diverging; apical margin sub-serrate. Undersurface with close shallow punctures, moderately covered with medium length hair; last abdominal segment broadly truncate in both sexes.

Size: Males 9.1 ± 0.20 x 3.3 ± 0.07 mm (14). Females 9.4 ± 0.25 x 3.5 ± 0.09 mm (14).

Distribution: Western Australia.

General remarks: Grouped with *S. acuticeps* Saunders, but is a narrower species.

Specimens examined: Types only.

Stigmodera (Castiarina) georgiana sp. nov.

FIGS 1H, 4H

Types: Holotype: ♂, Coral Bay, W. Aust., 29.vii.1977, *K. & E. Carnaby*, SAM I 21094. Allotype: ♀, Karang Stn, Shark Bay, W. Aust., on *Acacia* sp., 3.x.1957, *S. Barker*, SAM I 21095. Paratypes: 1 ♂ & 1 ♀, 2 km east Horrock's Beach, W. Aust., 21.ix.1958, *D. H. Edward*, SAM; 1 ♀, Carnarvon, W. Aust., 8.viii.1962, *F. H. Uther Baker*, SAM; 1 ♂, Wooramal, W. Aust., 18.viii.1962, *F. H. Uther Baker*, SAM; 1 ♀, 48 km south Carnarvon, W. Aust., 15.ix.1969, *F. H. Uther Baker*, SAM; 1 ♂, Wahroonga Stn, Gascoigne district, W. Aust., 17.ix.1969, *F. H. Uther Baker*, SAM; 1 ♀, Coral Bay, W. Aust., 29.vii.1977, *K. & E. Carnaby*, KC; 1 ♂, Dirk Hartog Isl., W. Aust., 6.ix.1972, *A. S. George*, WADA; 4 ♂ & 3 ♀, Marloo Stn, Wurarga, W. Aust., 1931–1941, *A. Goerling*, ANIC; 1 ♂, Geraldton, W. Aust., 1914, *Clarke*, ANIC; 2 ♀, Lake Austin, W. Aust., *H. W. Brown*, NMV; 2 ♂, Cue, W. Aust., *H. W. Brown*, NMV; 1 ♂, Geraldton, W. Aust., *J. Clark*, NMV; 1 ♀, W. Aust., ANIC.

Colour: Head, antennae, pronotum, scutellum, undersurface and legs black or blue-green with blue reflections. Elytra deep yellow with following black markings all with blue reflections: basal margin; premedial fascia, reduced to spot in middle of each elytron at shoulder and one on suture in some specimens; post-medial fascia reaching margin, projecting forwards in middle of each side and projecting forwards and backwards along suture; preapical mark covering apices and spines, last two marks connected down suture, fascia may or may not be connected down suture. Hairs silver.

Shape and sculpture: Head closely punctured with narrow, shallow groove between eyes, slightly ridged on inside of each antennal cavity, muzzle short. Pronotum with shallow punctures and minute median basal depression, with unpunctured median glabrous line from base to middle; projecting forwards in middle of apical margin, basal margin barely bisinuate; laterally rounded and narrowed from base to apex, widest part 1/3 distance from base. Scutellum shield-shaped, concave in middle, without punctures and glabrous. Elytra punctate-striate, intervals convex more so at apex than

base, with shallow punctures; laterally angled out from base, rounded at shoulder then concave until after middle, rounded and tapered to apex which is bispinose; marginal spine large, sutural spine very small, rounded and indented between; apices slightly diverging. Undersurface with shallow punctures, sparsely haired, hair long at anterior part, short on abdomen; last abdominal segment truncate and slightly indented in male, bilobed and pointed in female.

Size: Males 12.7 ± 0.22 x 4.7 ± 0.09 mm (12). Females 14.3 ± 0.32 x 5.4 ± 0.13 mm (13).

Distribution: Western Australia.

General remarks: This species is grouped with *S. longicollis* Saunders, *S. propinqua* Carter, *S. perlonga* Carter, *S. domina* Carter. It is smaller than all but *S. perlonga* but is comparatively wider than that species. Named after Dr R. W. George.

Specimens examined: Types only.

Stigmodera (Castiarina) verdiceps sp. nov.

FIGS 1I, 4I

Types: Holotype: ♂, Port Samson, W. Aust., 23.xii.1946, bred out of *Acacia* sp., *H. W. Brown*, SAM I 21096. Allotype: ♀, W. Aust., i.1947, *W. du Boulay*, ANIC. Paratypes: 3 ♂, same data as holotype, SAM; 1 ♂, same data as allotype, ANIC.

Colour: Head green, antennae dark brown with green reflections. Pronotum, scutellum, undersurface and legs green; hairs silver. Elytra yellow with following black markings which have blue reflections: anterior margin; post-medial fascia, reaching margin and expanded forwards in middle of each elytron and on suture; large apical mark connected along suture to fascia.

Shape and sculpture: Head closely punctured with median groove between eyes and ridged on inside of each antennal cavity, muzzle short. Pronotum closely punctured with small median basal depression projecting forwards as short impressed line; basal notch on each side, closer to margin than suture; projecting forwards in middle of anterior margin; basal margin bisinuate; laterally pinched in at base, rounded at apex and widest in middle. Scutellum heart-shaped and depressed in middle at anterior edge, without punctures. Elytra punctate-striate, intervals convex, more so at apex than at base; laterally angled out from base, rounded at shoulder then concave until after middle, rounded to apex which is bispinose; marginal spine slightly larger than sutural spine, rounded and indented between; apices diverging; margin sub-serrate from edge of apical mark to spines. Undersurface closely and shallowly punctured, sparsely haired; last abdominal segment broadly truncate and slightly indented in middle in males, narrowly truncate and indented in females.

Size: Males 12.3 ± 0.25 x 4.4 ± 0.08 mm (5). Female 14.3 x 5.2 mm (1).

Distribution: Western Australia.

General remarks: Grouped with *S. georgiana* Barker and its related species, but is cylindrical, narrower and bispinose.

Specimens examined: W. Aust.; Types; 1 ♂, Broome, i.1947, *H. W. Brown*, SAM.

Stigmodera (Castiarina) macmillani sp. nov.

FIGS 2A, 4J

Types: Holotype: ♂, Wialki, W. Aust., 21.ix. 1970, *S. Barker*, SAM I 21097. Allotype: ♀, Wialki, W. Aust., 17.ix.1957, *S. Barker*, SAM I 21098. Paratypes: 2 ♀, Northam, W. Aust., xi.1938, *C. G. Jessup*, SAM; 1 ♂, Meckering, W. Aust., 4.xi.1955, *R. P. McMillan*, SAM; 1 ♂, Badjaling, W. Aust., 30.ix.1970, *S. Barker*, SAM; 1 ♀, 10 km east Ravensthorpe, W. Aust., 16.xii.1975, *S. Barker*, SAM.

Colour: Head, antennae, pronotum, scutellum, undersurface and legs, dull bronze, green or blue. Elytra yellow with red margin and with following black markings: basal margin; premedial fascia expanded at marginal end into vitta reaching anterior margin forwards and lateral margin backwards, enclosing yellow basal mark at shoulder and elongate, predominantly red mark at shoulder; post-medial fascia touching margin in some specimens, not in others; preapical spade-shaped mark. Fascia connected down suture, preapical mark expanded down suture to apices in some specimens, not in others.

Shape and sculpture: Head closely punctured with shallow groove between eyes, muzzle short. Pronotum closely punctured with very small basal depression projecting forwards as glabrous line to middle and as shallow impressed line from middle to apex; no basal notches but glabrous triangular areas on each side at base closer to margin than centre; anterior margin straight; basal margin barely bisinuate; laterally angled inwards from base, then parallel-sided, rounded at middle and narrowed to apex, no hairs on dorsal surface. Scutellum shield-shaped, without punctures.

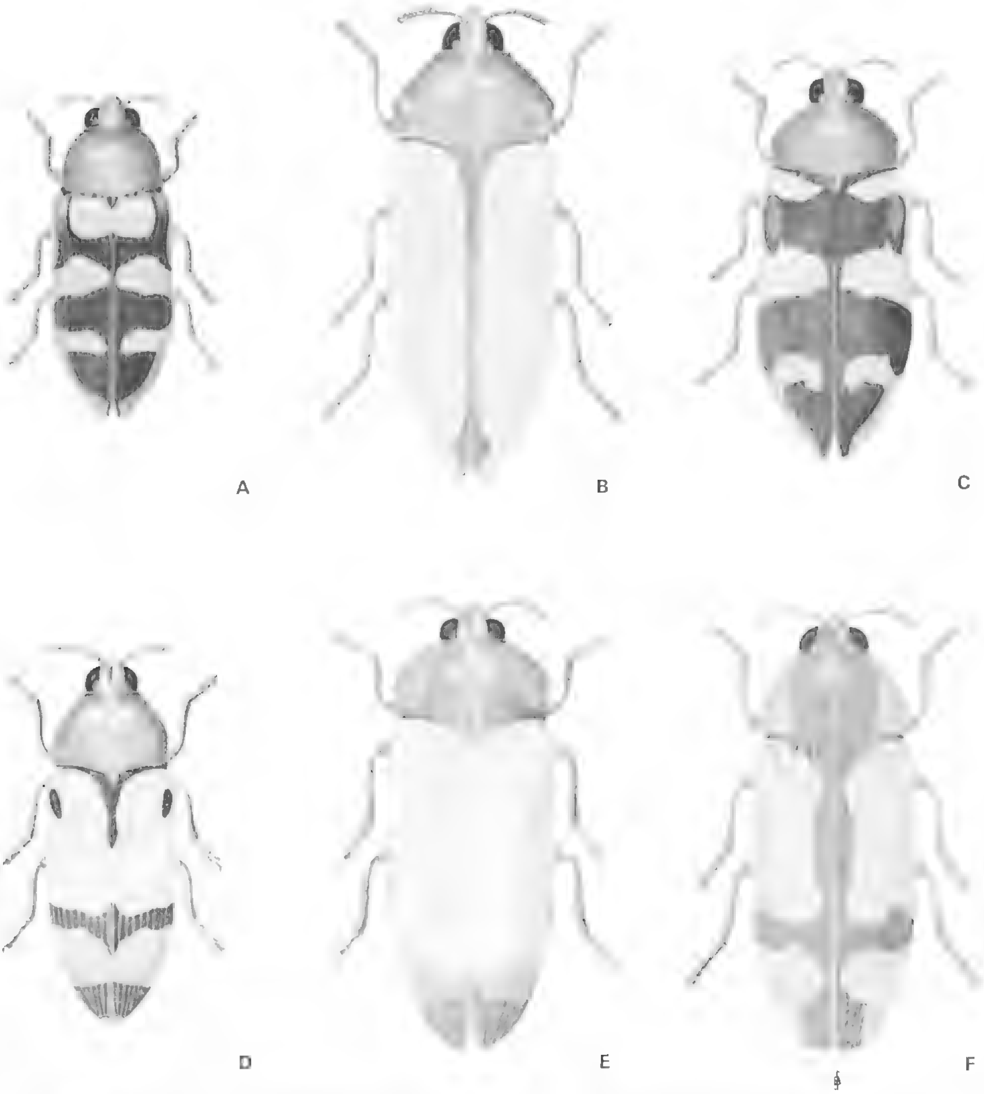

Fig. 2. x 3 natural size. A. *Stigmodera macmillani* sp. nov. B. *Stigmodera occidentalis* sp. nov. C. *Stigmodera ovata* sp. nov. D. *Stigmodera walfordi* sp. nov. E. *Stigmodera brooksi* sp. nov. F. *Stigmodera carnabyi* sp. nov.

glabrous, concave at upper edge. Elytra punctate-striate, intervals rounded, more so at base than at apex, with shallow punctures throughout their length; laterally angled out from base, rounded at shoulder, then concave until after middle, rounded to apex which is bispinose; sutural spine larger than marginal spine, indented and rounded between; apices barely diverging. Undersurface with close shallow punctures except on edges of abdominal segments which are glabrous, rest densely covered with long hair. Last abdominal segment truncate in male, rounded in female.

Size: Males 12.6 ± 1.01 x 4.7 ± 0.27 mm (3). Females 13.0 ± 0.38 x 4.9 ± 0.22 mm (4).

Distribution: Western Australia.

General remarks: Grouped with *S. simulata* L. & G. but is a smaller species, pronotum glabrous and not bulbous at the sides, apical part of elytra more rounded. Named after Mr R. P. McMillan.

Specimens examined: Types only.

Stigmodera (Castiarina) occidentalis sp. nov.
FIGS 2B, 4K

Types: Holotype: ♂, Stirling Range, W. Aust., 7.i.1971, *K. & E. Carnaby,* SAM I 21099. Allotype: ♀, 6 km west Wannamal, W. Aust.,

on *Nuytsia floribunda*, 10.xii.1970, *S. Barker*, SAM I 21100. Paratypes: 1 ♂ & 2 ♀, Stirling Range, W. Aust., 7.i.1971, *K. & E. Carnaby*, SAM; 1 ♀, 1 km south Bull's Creek, W. Aust., on *Nuytsia floribunda*, 1.xii.1957, *S. Barker*, SAM; 1 ♀, Jarrahdale, W. Aust., on *Agonis* sp., 21.xi.1954, *S. Barker*, SAM; 4 ♀, 6 km west Wannamal, W. Aust., on *Nuytsia floribunda*, 10 & 15.xii.1970, *S. Barker*, SAM; 4 ♂ & 3 ♀, Stirling Range, W. Aust., 12.i.1971, *K. & E. Carnaby*, ANIC; 1 ♀, Perth, W. Aust., *H. W. Brown*, ANIC; 1 ♀, Mt Ragged, W. Aust., 30.x.1977, *J. F. Lawrence*, ANIC; 1 ♀, Stirling Range, W. Aust., 7.i.1971, *K. & E. Carnaby*, GA; 1 ♂, South Perth, W. Aust., 17.xii.1906, *H. M. Giles*, NMV; 2 ♀, Kalamunda, W. Aust., *H. W. Brown*, NMV.

Colour: Male: Head, antennae, scutellum, undersurface and legs green, blue-green or blue. Female: Head, antennae, scutellum, undersurface and legs, green with yellow reflections. Elytra in both sexes yellow with narrow anterior margin dark blue and same along suture, expanded in preapical area to form diamond-shaped spot. Hairs silver.

Shape and sculpture: Head closely punctured, with shallow groove between eyes, ridged on inside of each antennal cavity, muzzle short. Pronotum closely punctured with large, shallow fovea in middle of each side towards base, small median basal fovea, small basal notch nearly one-half way from margin to centre, on each side; projecting forwards in middle of apical margin, basal margin bisinuate; laterally inflated before middle, rounded and tapered to apex, tapered then turned outwards at base. Scutellum heart-shaped, with few punctures, concave in middle. Elytra punctate-striate, intervals smooth and mainly flat; laterally barely angled outwards from base, rounded at shoulder and concave until after middle, tapered to apex which is bispinose; marginal spine larger than sutural, rounded and indented between. Undersurface smooth with shallow punctures and few short hairs; last abdominal segment truncate and slightly pressed in, in male, rounded in female.

Size: Males 17.5 ± 0.37 x 6.4 ± 0.13 mm (7). Females 18.9 ± 0.37 x 7.0 ± 0.16 mm (16).

Distribution: Western Australia.

General remarks: Grouped with *S. variopicta* Thomson but is larger than that species, has a bulbous pronotum and a constant sutural mark.

Specimens examined: Types only.

Stigmodera (Castiarina) ovata sp. nov.

FIG. 2C

Types: Holotype: ♂, Hamelin Pool, W. Aust., 9.ix.1970, *K. & E. Carnaby*, SAM I 21101. Allotype: ♀, Marloo Stn, Wurarga, W. Aust., 1931–1941, *A. Goerling*, ANIC. Paratypes: 1 ♀, 61 km NE Wubin, W. Aust., 18.x.1977, *K. T. Richards*, WADA; 1 ♀, Lake Bryde, W. Aust., 5.xi.1972, *K. & E. Carnaby*, KC; 1 ♀, Hamelin Pool, W. Aust., 10.ix.1971, *K. & E. Carnaby*, KC.

Colour: Head dull bronze, apex of muzzle blue-green. Antennae dull bronze except basal segment which is blue-green. Pronotum and scutellum dull bronze. Elytra yellow with following black markings: narrow basal margin; premedial fascia not reaching margin; post-medial fascia, convex forwards; apical spade-shaped mark extending down suture to extreme tip and connected to second fascia along suture; red around entire margin. Undersurface: sternum dull bronze; abdomen red-brown; legs blue-green; hairs silver.

Shape and sculpture: Head closely punctured with wide median groove between eyes, ridged on inside of antennal cavities, muzzle moderately elongate. Pronotum closely punctured with small median basal depression and basal notch on each side closer to margin than centre; apical margin angled forwards at sides, projecting forwards in middle, basal margin angled forwards from centre on each side, two sides straight; laterally indented at base, rounded and bulbous 1/3 distance from base, tapered to apex. Scutellum heart-shaped, not punctured, indented at front edge in middle. Elytra punctate-striate, intervals convex, more so at base than apex, with rows of punctures; laterally angled outwards from base, rounded at shoulder, concave until after middle, rounded to apex which is without spines; apices diverging. Undersurface with close shallow punctures, moderately covered with short hair. Last abdominal segment truncate in male, rounded in female.

Size: Male 13.9 x 5.8 mm (1). Females 15.1 ± 0.45 x 6.2 ± 0.28 mm (4).

Distribution: Western Australia.

General remarks: A broad-bodied species which cannot be grouped with any other.

Specimens examined: Types only.

Stigmodera (Castiarina) walfordi sp. nov.

FIGS 2D, 4L

Types: Holotype: ♀, Paluma, Qld, 15.i.1967, *A. Walford-Huggins*, SAM I 21102. Paratypes: 1 ♂, no data, BM; 1 ♂, Qld, BM; 1 ♀, Townsville, Qld, 29.xii.1902, *F. P. Dodd*, BM; 1 ♀, North Qld, BM; 2 ♀, Paluma, Qld, 15.i.1967, *A. Walford-Huggins*, AWH; 3 ♀, Paluma, Qld, *E. E. Adams*, EA; 1 ♀, Ewan Rd, 14 km west Paluma, Qld, 20.xii.1968, *J. A. G. Brooks*, ANIC; 1 ♀, Mt Spec, Qld, 12.i.1969, *J. G. Brooks*, NMV.

Colour: Head, pronotum, scutellum bronze with purple reflections. Antennae bronze, 1st and 2nd segments with blue reflections, rest with purple reflections. Elytra yellow with following markings all black with blue and/or purple reflections: an elongate mark on each shoulder angled inwards towards apex; post-medial fascia reaching margin from suture; mark covering whole apex; anterior margin and all or part along suture; most of margin red and most of area between fascia and apical mark red. Undersurface bronze with purple reflections at anterior part, abdomen testaceous. Legs: femora bronze with purple reflections, tibia same but with blue tips; tarsi blue; hairs silver.

Shape and sculpture: Head closely punctured with median groove between eyes, ridged on inside of each antennal cavity, muzzle short. Pronotum closely punctured with small basal fovea projecting forwards to middle as glabrous line and as impressed line from middle to apex; anterior margin projecting forwards in middle; basal margin bisinuate; laterally concave from base, bulbous and rounded before middle, rounded and narrowed to apex. Scutellum shield-shaped, concave in middle of front edge, without punctures. Elytra punctate-striate, intervals convex, more so at apex than at base, wrinkled more so at apex than at base; laterally slightly angled out from base, rounded at shoulder then concave until after middle, rounded to apex which is bispinose; spines small and rounded between; apices slightly diverging; apical margin sub-serrate. Undersurface: closely punctured; moderately hairy, hairs short. Last abdominal segment rounded in both sexes.

Size: Males 15.5 x 5.9 mm (2), Females 15.8 ± 0.20 x 6.0 ± 0.07 mm (10).

Distribution: Queensland.

General remarks: Grouped with *S. straminea* MacLeay but is larger than that species, has ridges on insides of antennal cavities, the pronotum is closely punctured and is not bulbous and the elytral markings are different. Named after Mr A. Walford-Huggins.

Specimens examined: Types only.

Stigmodera (Castiarina) brooksi sp. nov.

FIGS 2E, 4M

Types: Holotype: ♂, 16 km west Running River, Paluma Range, Qld, 12.i.1969, *E. E. Adams*, SAM I 21103. Allotype: ♀, 16 km west Running River, Paluma Range, Qld, 12.i.1969, *E. E. Adams*, SAM I 21104. Paratypes: 3 ♂ & 2 ♀, Paluma, Qld, 15.i.1967, *A. Walford-Huggins*, AWH; 1 ♂, Ewan Rd, Mt Spec, Qld, 8.i.1969, *J. G. Brooks*, SAM; 1 ♂, Mt Spec, Qld, 16.i.1965, *J. A. G. Brooks*, JB; 2 ♀, Mt Spec, Qld, 3.i.1966 & 6.i.1966, *J. A. G. Brooks*, JB; 1 ♂, Ewan Rd, 19 km west Paluma, Qld, 3.i.1966, *J. A. G. Brooks*, ANIC; 1 ♂, Ewan Rd, 18 km west Paluma, Qld, 12.i.1966, *J. A. G. Brooks*, ANIC; 2 ♂, Mt Spec, Qld, 23.i.1966 & 5.i.1967, *J. G. Brooks*, BM; 1 ♂, Ewan Rd, Mt Spec, Qld, 12.i.1969, *J. G. Brooks*, NMV.

Colour: Head dark blue with green reflections. Antennae green. Pronotum bicolorous: brick-red at sides; black in middle with blue reflections at posterior margins. Elytra mainly yellow, with dark blue basal margin, red curved band towards apex, apex blue. Undersurface bicolorous: lateral prosternum bright red, last three abdominal segments predominantly same, laterally deep blue; hairs silver.

Shape and sculpture: Head with shallow punctures, median groove between eyes, ridged on inside of antennal cavities, muzzle short. Pronotum with shallow punctures; with median impressed line projecting forwards to apex from basal depression; basal notches on each side almost ⅓ way from margin to centre; projecting forwards in middle of apical margin; basal margin bisinuate; laterally inflated in middle, rounded anteriorly, straight at base. Scutellum heart-shaped, indented in middle of anterior margin, with punctures. Elytra striate-punctate, intervals slightly convex but smooth; laterally angled outwards from base, rounded at shoulder, concave before middle, rounded and tapered from middle to apex which has no spines; apices diverging slightly; apical margin sub-serrate. Undersurface: with shallow punctures, smooth; slightly hairy. Last abdominal segment rounded in both sexes.

Size: Males 18.5 ± 0.19 x 7.1 ± 0.08 mm (11). Females 19.7 ± 0.42 x 8.0 ± 0.34 mm (5).

Distribution: Queensland.

General remarks: Grouped with *S. analis* Saunders but is a larger species, has a red band on the apex of the elytra and bicolorous undersurface. Named after the late Mr J. G. Brooks.

Specimens examined: Types only.

Stigmodera (Castiarina) carnabyi sp. nov.

FIGS 2F, 4N

Types: Holotype: ♂, Jerramungup, W. Aust., 15.i.1971, *K. & E. Carnaby*, ANIC. Allotype: ♀, Jerramungup, W. Aust., 2.xii.1970, *K. & E. Carnaby*, SAM I 21105. Paratypes: 2 ♀, Jerramungup, W. Aust., 2.xii.1970, *K. & E. Carnaby*, 1 KC, 1 EA; 1 ♂ & 1 ♀, same data as holotype, ANIC.

Colour: Head dark blue. Antennae: basal two segments dark blue; remainder black with yellow-green reflections. Pronotum blue in middle, thick lateral margin red-brown. Scutellum black with blue reflections. Undersurface and legs deep blue. Hairs silver. Elytra red-brown with the following black markings with blue reflections; narrow basal border; post-medial fascia; apical mark; marks all connected down suture with slight bulge in pre-medial area.

Shape and sculpture: Head with close shallow punctures, shallow groove between eyes, muzzle short. Pronotum with shallow punctures; two flat patches near base and close to basal angles without punctures; small basal depression; projecting forwards in middle of apical margin; basal margin barely bisinuate; laterally rounded from base, expanded 1/3 distance from base then tapered to apex. Scutellum elongate, heart-shaped and depressed in middle of basal edge, without punctures. Elytra punctate-striate, intervals convex at base, flatter at apex, intervals wrinkled and punctured at shoulder and along margin, laterally slightly angled out from base, rounded at shoulder, then concave until after middle, then rounded to apex which is truncate and without spines; apices barely diverging. Undersurface with shallow punctures and few short hairs. Last abdominal segment truncate in male, rounded in female.

Size: Males 16.3 x 6.3 mm (2). Females 18.2 ± 0.29 x 7.2 ± 0.13 mm (4).

Distribution: Western Australia.

General remarks: Cannot be grouped with any other species. Named after Mr K. Carnaby.

Specimens examined: Types only.

Stigmodera (Castiarina) uptoni sp. nov.

FIGS 3A, 4O

Types: Holotype: ♂, 55 km NE Barrow Creek, N.T., 12.x.1972, *M. S. Upton*, ANIC. Allotype: ♀, 55 km NE Barrow Creek, N.T., 12.x.1972, *M. S. Upton*, ANIC. Paratypes: 1 ♂ & 3 ♀, same data as holotype, 1 ♀ SAM, 1 ♂ & 2 ♀ ANIC.

Colour: Head mainly coppery, apex of muzzle blue-green. Antennae black. Pronotum coppery at sides with triangular patch in middle dark blue, with greenish margin. Scutellum dark blue. Elytra yellow with following dark blue markings: premedial spot on each elytron; post-medial fascia reaching margin and expanded at margin and on suture; apical mark covering spines and connected along suture to fascia. Undersurface and legs coppery-violet; tarsi black; hairs silver.

Shape and sculpture: Head closely punctured with median groove between eyes, muzzle elongate. Pronotum closely punctured at sides, larger and deeper than in middle where they are sparse and shallow and surface glabrous; median basal depression and basal notches close to middle of each side; apical margin projecting forwards in middle; basal margin bisinuate; laterally tapered from base to apex, slightly rounded near apex. Scutellum shield-shaped, without punctures, concave in middle of front edge. Elytra punctate-striate, punctures large and very deep, intervals convex and evenly rounded and glabrous; laterally angled out from base, rounded at shoulder, then slightly concave until after middle, then rounded to apex which is bispinose; marginal spine greatly enlarged and rounded on outside, pointed inside with slight indentation to very small sutural spine; apices slightly diverging. Undersurface with shallow punctures, lightly haired; last abdominal segment rounded in both sexes; 5th tarsal segment is as long as combined length of other 4 segments.

Size: Males 10.4 x 3.8 mm (2). Females 10.7 ± 0.28 x 3.8 ± 0.19 mm (4).

Distribution: Northern Territory.

General remarks: Grouped with *S. quadrifasciata* Saunders but differs from that species being smaller, with enlarged marginal spine and elongate 5th tarsal segment. All specimens examined were collected dead from the insides

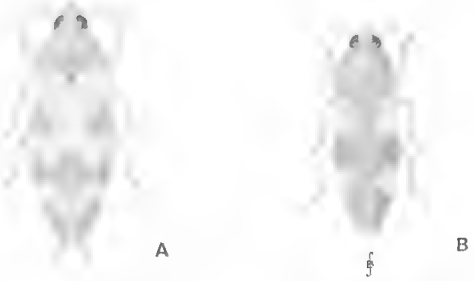

Fig. 3. x 3 natural size. A. *Stigmodera uptoni* sp. nov. B. *Stigmodera borealis* sp. nov.

of tubular road markers which also contained other dead insects. As spiders were not present they may have been dropped by predatory insects, possibly Asilid flys. Named after Mr M. S. Upton.

Specimens examined: N.T.; Types; 3 damaged specimens, same data as holotype ANIC.

Stigmodera (Castiarina) borealis sp. nov.

FIG. 3B

Types: Holotype: ♀, 2200 m elevation, Mt Otto, New Guinea, 22.vi.1955, *J. L. Gressit*; BPBM Bishop 10653.

Colour: Head. antennae, pronotum, scutellum, undersurface and legs dark blue. Elytra with following dark blue markings: thick basal fascia; thick fascia at middle; broad apical mark all connected broadly down suture; two large red spots on each elytron, one pre- and one post-medial, touching margin but not reaching suture. Undersurface hairs silver.

Shape and sculpture: Head shallowly punctured, glabrous, with median groove between

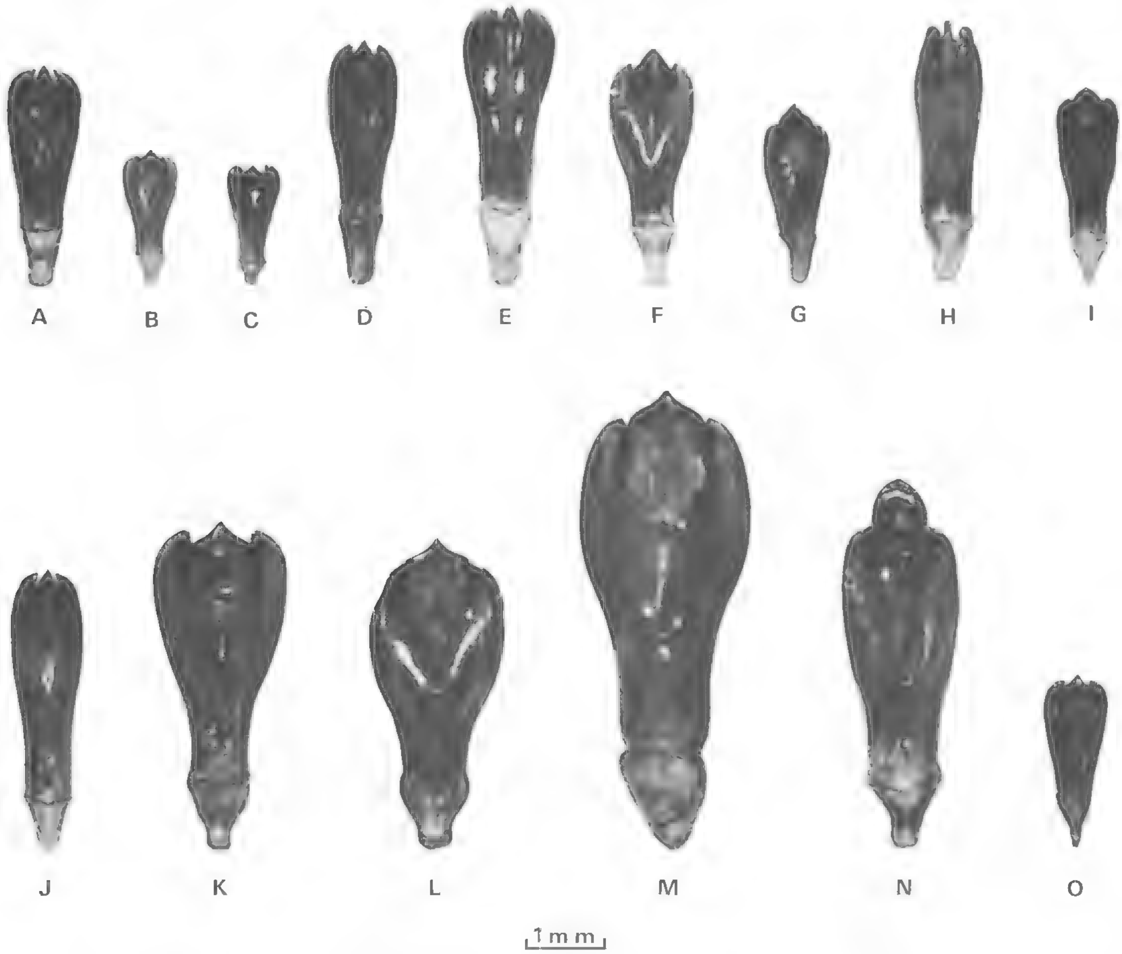

Fig. 4. Photomicrographs of male genitalia of the following *Stigmodera (Castiarina)* species: A. *planipes*, B. *crockerae*, C. *nigriceps*, D. *metallica*, E. *bakeri*, F. *richardsi*, G. *subacuticeps*, H. *georgiana*, I. *verdiceps*, J. *macmillani*, K. *occidentalis*, L. *walfordi*, M. *brooksi*, N. *carnabyi*, O. *uptoni*.

eyes, muzzle short. Pronotum shallowly punctured and glabrous, punctures larger at sides than in middle, with median basal depression and shallow rounded depression on each side near base; anterior margin projecting forwards broadly in middle; basal margin bisinuate; laterally pinched in at base, rounded until after middle and rounded to apex. Scutellum heart-shaped, depressed in middle of anterior margin, glabrous. Elytra punctate-striate intervals convex, more so at base than at apex; laterally angled out from base, rounded at shoulder, then concave until after middle, rounded to apex which is bispinose; marginal spine larger than sutural spine, interval between comparatively broad and straight; apical half of margin serrate; apices barely diverging. Undersurface shallowly punctured and moderately covered with short hair. Last abdominal segment broadly truncate in female.

Size: Female 8.7 x 2.8 mm (1).

Distribution: New Guinea.

General remarks: Cannot be grouped with any other species.

Specimens examined: Type only.

Sub-genus CASTIARINA LaPorte & Gory 1837

abdominalis Saunders 1868, *J. Linn. Soc.* 9, 467	W.A., S.A., V., Q., N.S.W.
unica Kerremans 1898, *Annls Soc. ent. Belg.* 42, 150	
acuminata Kerremans 1898, *Annls Soc. ent. Belg.* 42, 142	Q., N.S.W.
acuta Deuquet 1956, *Proc. Linn. Soc. N.S.W.* 81, 154	N.S.W.
acuticeps Saunders 1869, *Insect. Saund.* 3, 19	W.A.
odewahni Obenberger 1928, *Arch. Naturgesch.* 1926, 92, 330	
acuticollis Carter 1916, *Trans. R. Soc. S. Aust.* 40, 133	Q.
adamsi Deuquet 1957, *Proc. Linn. Soc. N.S.W.* 82, 189	Q.
adelaidae Hope 1846, *Trans. ent. Soc. Lond.* 4, 212	S.A., V., N.S.W., T.
aeneicornis Saunders 1868, *J. Linn. Soc.* 9, 472	V., N.S.W.
laudabilis Kerremans 1898, *Annls Soc. ent. Belg.* 42, 146	
aeraticollis Carter 1930, *Proc. Linn. Soc. N.S.W.* 55, 182	W.A.
affabilis Kerremans 1898, *Annls Soc. ent. Belg.* 42, 141	Q.
simplex Kerremans 1902, *Genera Insect.* 12, 210	
alexandri Carter 1916, *Trans. R. Soc. S. Aust.* 40, 119	W.A., S.A.
alternecosta Thomson 1879, *Typ. Bupr. App.* 1a, 35	N.S.W., Q.
alacris Kerremans 1890, *Bull. Soc. ent. Belg.* 1890, 47	
disjecta Kerremans 1890, *Bull. Soc. ent. Belg.* 1890, 48	
alternecostata Kerremans 1892, *Mém Soc. r. ent. Belg.* 1, 143	
quadrinotata Blackburn 1892, *Trans. R. Soc. S. Aust.* 15, 49	
libens Kerremans 1902, *Genera Insect.* 12, 209	
amabilis L & G 1837, *Mon. Bupr.* 2, 19	W.A.
amplipennis Saunders 1868, *J. Linn. Soc.* 9, 480	S.A., V., N.S.W., Q.
amplicollis Carter 1931, *Aust. Zool.* 6, 107	
analis Saunders 1869, *Insect. Saund.* 3, 7	Q.
marginicervex Thomson 1879, *Typ. Bupr. App.* 1a, 31	
anchoralis L & G 1837, *Mon. Bupr.* 2, 26	W.A.
arborifera Blackburn 1892, *Trans. R. Soc. S. Aust.* 15, 51	
agrestis Kerremans 1898, *Annls Soc. ent. Belg.* 42, 140	
tantilla Obenberger 1922, *Arch. Naturgesch.* 1922, 88, 116	
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  melbournensis Thomson 1879, *Typ. Bupr. App.* 1a, 34
bakeri Barker 1979, *Trans. R. Soc. S. Aust.* 103, 5 — W.A.
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  postica Thomson 1879, *Typ. Bupr. App.* 1a, 37
balthasari Obenberger 1928, *Arch. Naturgesch.* 1926, 92, 330 — W.A.
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  bicincta (Boisduval) 1835, Voyage de l'Astrolobe, 89
  bicingulata L & G 1837, *Mon. Bupr.* 2, 30
  dejeani Gory 1841, *Mon. Bupr.* 4, err. add.
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    haroldi Saunders 1871, *Cat. Bupr. Syn. Syst.*, 74
    viridiventris Saunders 1869, *Insect. Saund.* 3, 20
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    stillata Blackburn 1890, *Trans. R. Soc. S. Aust.* 13, 148
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    deyrollei Thomson 1879, *Bull. Soc. ent. Fr.* 9, 125
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obsepta Kerremans 1890, *Bull. Soc. ent. Belg.* 1890, 44		Q.
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octosignata Carter 1919, *Proc. Linn. Soc. N.S.W.* 44, 139		Q.
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picta L & G 1837, *Mon. Bupr.* 2, 46		W.A.
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placida Thomson 1879, *Typ. Bupr. App.* 1a, 33		W.A.

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producta Saunders 1868, *J. Linn. Soc.* 9, 482	N.S.W., Q.
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propinqua Carter 1916, *Trans. R. Soc. S. Aust.* 40, 124	S.A.
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cyanicollis (Boisduval) 1835, Voyage de l'Astrolobe, 91	
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prudens Kerremans 1898, *Annls. Soc. ent. Belg.* 42, 152	
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crenata L & G 1837, *Mon. Bupr.* 2, 39
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lais Thomson 1879, *Typ. Bupr. App.* 1a, 33
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fraterna Kerremans 1890, *Bull. Soc. ent. Belg.* 1890, 46
distinguenda Thomson 1879, *Typ. Bupr. App.* 1a, 34
ravilla Obenberger 1922, *Arch. Naturgesch.* 1922, 88, 117
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colorata Kerremans 1898, *Annls Soc. ent. Belg.* 42, 141

tincticauda Carter 1916, *Trans. R. Soc. S. Aust.* 40, 136 .... W.A.
titania Carter 1916, *Trans. R. Soc. S. Aust.* 40, 134 .... N.S.W., Q.
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tricolor (Kirby) 1818, *Trans. Linn. Soc.* 12, 455 .... N.S.W.
curta Saunders 1868, *J. Linn. Soc.* 9, 467
opima Kerremans 1902, *Genera Insect.* 12, 207
trifasciata L & G 1837, *Mon. Bupr.* 2, 38 .... W.A.
apicalis L & G 1837, *Mon. Bupr.* 2, 43
gravis Harold 1869, *Col. Heft.* 5, 124
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uptoni Barker 1979, *Trans. R. Soc. S. Aust.* 103, 13 .... N.T.
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variopicta Thomson 1878, *Typ. Bupr.*, 54 .... V., N.S.W.
venusta Carter 1914, *Proc. Linn. Soc. N.S.W.* 39, 84 .... Q.
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modesta Obenberger 1922, *Arch. Naturgesch.* 1922, 88, 122
verdiceps Barker 1979, *Trans. R. Soc. S. Aust.* 103, 8 .... W.A.
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Emendation of a name in the genus *Astraeus* L & G (Coleoptera: Buprestidae)

In my second paper on the genus *Astraeus* (*Trans. R. Soc. S. Aust.* 101: 13-14) I inadvertantly used an inappropriate termination for a new species name. I now emend this name *A. crockeri* Barker, to *A. crockerae* Barker.

Acknowledgments

I wish to thank the following people for assistance: Mr G. Gross, Dr E. Mathews, Dr S. J. Edmonds and Dr J. J. H. Szent-Ivany, South Australian Museum; Dr E. B. Britton, Dr J. Lawrence and Mr T. Weir, Division of Entomology, C.S.I.R.O.; Mr K. Dahms, Queensland Museum; Dr A. Neboiss and Mr A. A. Calder, National Museum of Victoria; Mr G. Holloway, Australian Museum, Sydney; Miss A. Green, Tasmanian Museum & Art Gallery, Hobart; Mr R. Green, Queen Victoria Museum & Art Gallery, Launceston; Dr L. Koch, Western Australian Museum; Mr R. D. Pope and Mr R. T. Thompson, British Museum (Natural History); Monsieur A. Descarpentries, Muséum National d'Histoire, Paris; Dr A. Cobos, Instituto de Aclimatación, Almeria, Spain; Dr R. Poggi, Museo Civico di Storia Naturale, Genova, Italy; Dr M. W. R. de V. Graham and Mr J. Ismay, Hope Department of Zoology (Entomology), University of Oxford; Dr T. Nyholm, Naturhistoriska Riksmuseet, Stockholm; Dr J. Jelinek, National Museum of Prague; Dr G. A. Samuelson, Bernice P. Bishop Museum, Honolulu; Dr Z. Kaszab, Hungarian Natural History Museum, Budapest; Mr A. Allwood, Department of Primary Industry, Darwin; Mr K. T. Richards, W.A. Department of Agriculture; Mr E. E. Adams, Edungalba; Mrs J. Harslett, Amiens; Dr F. H. Uther Baker, Applecross; Mr and Mrs J. Arnold, Wialki; Mr G. Burns, Mornington; Mrs A. E. Crocker and family, Balladonia Stn; Mr R. P. McMillan, Cottesloe; Mr and Mrs K. Carnaby, Wilga; Mr K. Haleley, Kiata; Mr T. J. Hawkeswood, Armidale; Mr C. G. L. Gooding, Warragul; Mr J. Macqueen, Toowoomba; Mr A. Walford-Huggins, Cairns; Mr J. A. G. Brooks, Cairns; Mr R. I. Storey, Mareeba; Dr E. Wollaston, Miss R. Altmann, Miss J. T. Mortlock, Mr P. Christy and Mr R. W. Inns, all of the University of Adelaide; I particularly want to thank Miss C. M. H. von Hayek of the British Museum (Natural History) for advice and for invaluable assistance with literature searches and type specimens; National Parks Board of Western Australia, for permission to collect in Flora Reserves; The Director, National Parks & Wildlife Service, South Australia, for permission to collect in National Parks; The Director, National Parks & Wildlife Service of New South Wales for permission to collect in the Warrumbungles National Park; The Australian Biological Resources Committee provided a grant-in-aid of research.

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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE MUNDALLIO SUBGROUP (NEW NAME) IN THE LATE PRECAMBRIAN BURRA GROUP OF THE MT LOFTY AND FLINDERS RANGES

BY ROBIN K. UPPILL

Summary

Three new formations, the Nathaltee Formation, the Nankabunyana Formation and the Yadlamalka Formation are proposed for the stratigraphic interval previously referred to as the Skillogalee Dolomite in the southern and northern Flinders Ranges, South Australia. These proposed formations and the existing formations referring to this stratigraphic interval in the Mt Lofty Ranges, comprise the Mundallio Subgroup.

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Summary

UPPILL, ROBIN K. (1979) Stratigraphy and depositional environments of the Mundallio Subgroup (new name) in the late Precambrian Burra Group of the Mt Lofty and Flinders Ranges. *Trans. R. Soc. S. Aust.* 103(2), 25-43, 28 February, 1979.

Three new formations, the Nathaltee Formation, the Nankabunyana Formation and the Yadlamalka Formation are proposed for the stratigraphic interval previously referred to as the Skillogalee Dolomite in the southern and northern Flinders Ranges, South Australia. These proposed formations and the existing formations referring to this stratigraphic interval in the Mt Lofty Ranges, comprise the Mundallio Subgroup.

The lower part of the Mundallio Subgroup has variable facies across the Adelaide Geosyncline from clastic to carbonate dominated. However the development of a shallow basin with similar water depths over wide areas, resulted in the widespread deposition of dolomite in the upper part of the subgroup, while magnesite deposition occurred in marginal and restricted areas. Numerous sandstone interbeds were deposited adjacent to major source areas.

Introduction

The Burra Group in South Australia is a major sedimentary cycle beginning with a basal sequence dominated by terrigenous clastics, and may unconformably overlie basement or older sedimentary sequences of the Callana Beds. This dominantly clastic sequence is overlain by a mixed carbonate-clastic sequence characterized by the presence of magnesite, particularly in the upper part. This latter sequence has been investigated by Howchin (1915), Mawson (1941, 1947), Forbes (1960, 1961) and Preiss (1973). The remainder of the Burra Group is a dominantly clastic sequence with variable development of dolomite. Within the Adelaide Geosyncline, the Burra Group has an extremely widespread distribution, from the southern Mt Lofty Ranges to the Peake and Denison Ranges, 750 km northwest of Adelaide.

The sedimentary sequence characterized by magnesite has almost as widespread a distribution as the Burra Group itself. The Skillogalee Dolomite was proposed by Wilson (1952) to refer to this interval in the Riverton-Clare region, and this nomenclature was followed by Mirams & Forbes (1964). Subsequently the term Skillogalee Dolomite has been used in other areas in which this sequence occurs with the exception of the Adelaide region (Forbes 1971). The Castambul Dolomite and Montacute Dolomite were proposed for this sequence in the Adelaide region (Mawson & Sprigg 1950). In some areas the Skillogalee Dolomite has been subdivided into two unnamed members (Coats *et al.* 1969). The correlation of sequences in other areas with the type section of the Skillogalee Dolomite has been based on the presence of dark grey dolomite, and magnesite. However detailed work still in progress by the author, indicates sufficient mappable lithological differences within the interval referred to as the Skillogalee Dolomite, to warrant the introduction of additional stratigraphic nomenclature. Murrell (1977)[1] discusses an unpublished nomenclature for this interval in the Willouran Ranges, and correlation of this

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[1] Murrel, B. (1977) Stratigraphy and tectonics across the Torrens Hinge Zone between Andamooka and Marree. Unpubl. Ph.D. thesis. Univ. of Adelaide.

TABLE 1.

Existing and proposed nomenclature within the Mundallio Subgroup.

	Mt Lofty Ranges		Southern Flinders Ranges	Northern Flinders Ranges	
MUNDALLIO SUBGROUP	Woolshed Flat Shale				
	Montacute Dolomite		Yadlamalka† Formation	Yadlamalka† Formation	Mirra* Formation
		Skillogalee Dolomite	Nathaltee† Formation	Nankabunyana† Formation	Tilterana* Sandstone
	Castambul Formation				Camel Flat* Shale

† Names proposed in this paper.
* Unpublished names, Murrell (1977).[1]

area with the remainder of the Adelaide Geosyncline will be discussed below.

Basis for revision

The sedimentary sequence deposited after the Aldgate Sandstone and its equivalents, and ending with the cessation of magnesite deposition, represents a very shallow water phase of sedimentation, encompassing smaller scale transgressive-regressive cycles. Sedimentation was characterized by a specific basin chemistry, with dolomite as the prevailing carbonate throughout the basin, while magnesite was precipitated on the margins. However facies changes between areas resulted because of variable influxes of terrigenous clastics, relative proximity to the basin margin, and tectonic influences on basin morphology and subsidence rates.

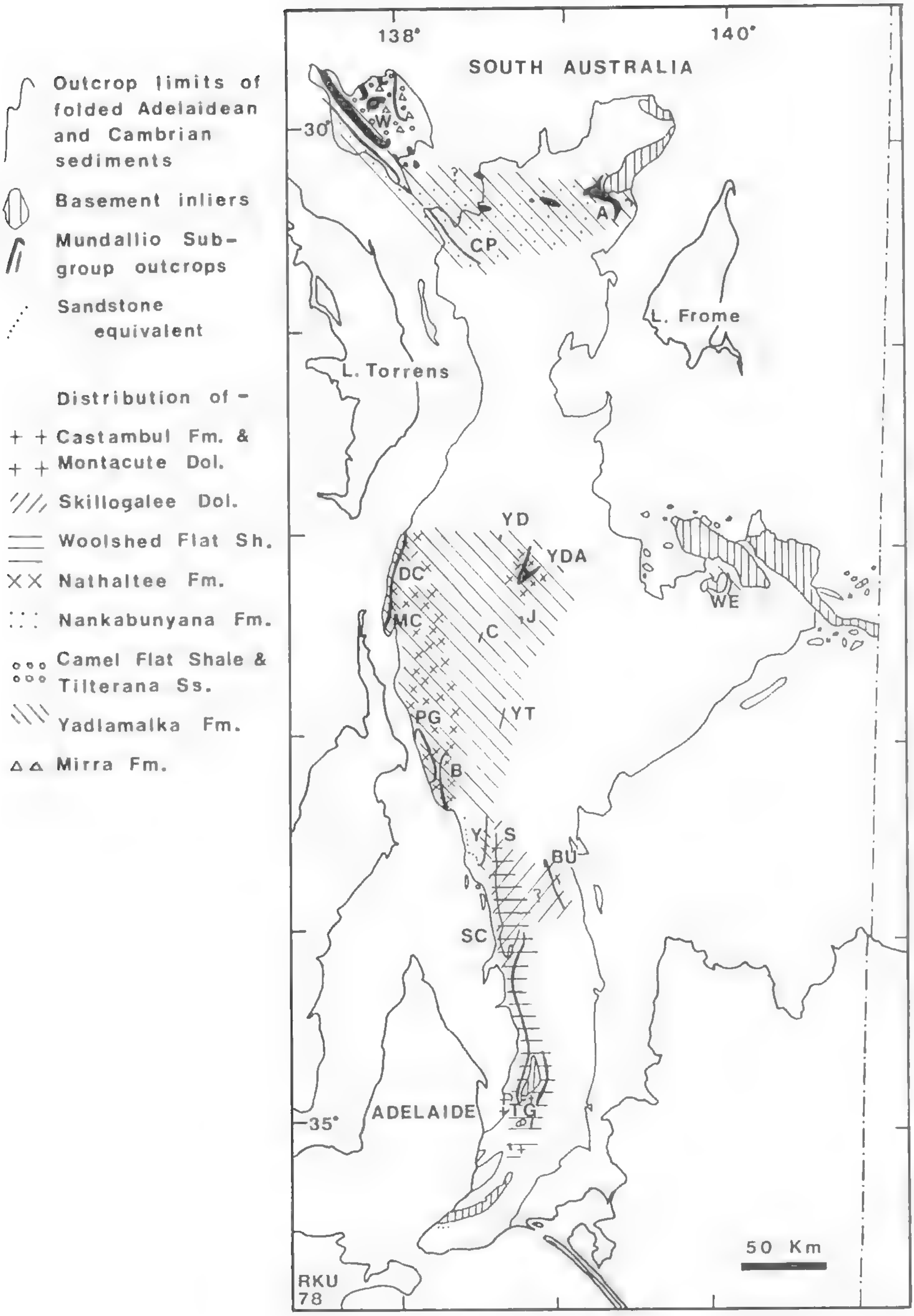
Within the southern and northern Flinders Ranges, the sedimentary interval referred to as the Skillogalee Dolomite, contains several lithologically distinct and mappable units, although intertonguing relationships occur. The application of a single formation name to this interval obscures the vertical and lateral relationships between these units, and the different depositional environments which they represent. Hence a revised stratigraphic nomenclature is proposed (Table 1), and the relationships between the existing and proposed formations are discussed below. The Mundallio Subgroup, after "Mundallio" H.S. 10 km northeast of Port Augusta, has been introduced because of the occurrence of these formations in a cycle of regressive, shallow-water, mixed carbonate-clastic sedimentation. The type sections of two of the proposed formations, are located 25 km north of "Mundallio" H.S, in the vicinity of Depot Creek (Fig. 2A), an area which has been used to illustrate the important features of this interval, to a much greater extent than the type section of the Skillogalee Dolomite in Skillogalee Creek. The two formations defined have excellent exposure, and one (the Yadlamalka Formation) is the most extensive formation in the proposed Mundallio Subgroup (Fig. 1).

Discussion and revision of existing formations

CASTAMBUL AND MONTACUTE DOLOMITES

This nomenclature was introduced by Mawson & Sprigg (1950), to refer to the two major dolomite horizons between the Aldgate Sandstone and the Stonyfell Quartzite in the Adelaide region. The present Burra Group nomenclature in this region is summarized by Forbes in Daily *et al.* (1976). The Castambul Dolomite is an essentially homogeneous, cream coloured, recrystallized dolomite with minor sandy and shaly intervals. The Montacute Dolomite is a more variable unit consisting of dark grey, variably recrystallized dolomites, fine-grained laminated magnesite, intraformational dolomite and magnesite conglomerates, and dolomite-cemented sandstones. Rapid vertical and lateral facies changes occur within the Montacute Dolomite. Both formations are of only localized occurrence (Fig. 1), with the most significant outcrops occurring in the Torrens Gorge area, where they are associated with siltstones and minor sandstones. Elsewhere in the Adelaide region, this

Fig. 1. Distribution map of the Mundallio Subgroup (excluding Peake-Denison Ranges). Locations W—Willouran Ranges, CP—Copley, A—Arkaroola, YD—Yednalue, YDA—Yednalue Anticline, WE—Weekeroo, DC—Depot Creek, MC—Mundallio Creek, C—Carrieton, J—Johnburg, YT—Yatina, PG—Port Germein Gorge, B—Beetaloo Reservoir, Y—Yacka, S—Spalding, SC—Skillogalee Creek, BU—Burra, TG—Torrens Gorge.


Outcrop limits of folded Adelaidean and Cambrian sediments
Basement inliers
Mundallio Sub-group outcrops
Sandstone equivalent
Distribution of -
Castambul Fm. & Montacute Dol.
Skillogalee Dol.
Woolshed Flat Sh.
Nathaltee Fm.
Nankabunyana Fm.
Camel Flat Shale & Tilterana Ss.
Yadlamalka Fm.
Mirra Fm.
138°
140°
SOUTH AUSTRALIA
30°
W
?
A
CP
L. Frome
L. Torrens
YD
YDA
DC
MC
C
J
WE
YT
PG
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Y
S
BU
?
SC
ADELAIDE
TG
35°
50 Km
RKU 78

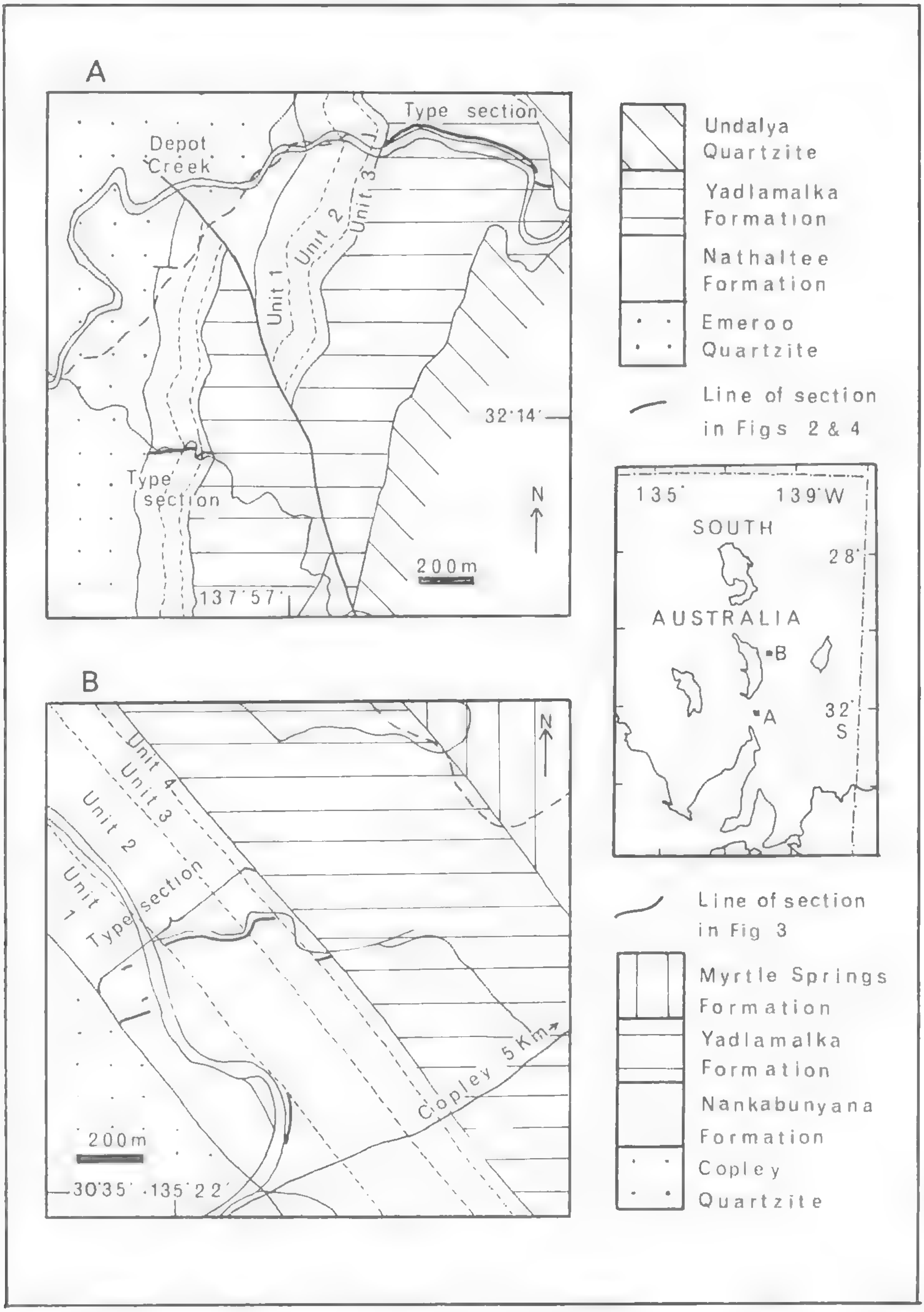


Fig. 2. Location map of proposed type sections.

sequence is dominated by siltstones of the Woolshed Flat Shale (see below).

In order to simplify the nomenclature proposed by Mawson & Sprigg (1950), it is proposed that the Castambul Dolomite be renamed the *Castambul Formation* and refer to the interval from the top of the Aldgate Sandstone to the base of the Montacute Dolomite in the Torrens Gorge area. Hence it will include the "unnamed slates" of Mawson & Sprigg (1950).

SKILLOGALEE DOLOMITE AND WOOLSHED FLAT SHALE

These formations were proposed by Wilson (1952) in the Riverton-Clare region. He described the Skillogalee Dolomite as "cream coloured fine- to medium-grained dense dolomites with occasional interbedded dolomitic shales . . in several areas notable blue-grey members appear in the uppermost sections of the formation" (Wilson 1952). The cream coloured dolomites, which comprise most of the formation, are extensively recrystallized, obliterating the original sedimentary textures and structures. Apart from a few poorly preserved stromatolites, clues to the nature of the original sediment are rare. The lenticular dark grey dolomites are less recrystallized, and originated as laminated mudstones (in the sense of Dunham, 1962) with minor stromatolitic horizons. Rare intraformational magnesite conglomerate is present. The outcrops in Skillogalee Creek extend northward to Spalding, and a similar sequence occurs south of Burra. The term Skillogalee Dolomite should refer to outcrops in these areas only, that is, where the dominant facies is cream coloured, recrystallized dolomite. Other outcrops which have previously been referred to as the Skillogalee Dolomite will be incorporated in the new formations proposed below.

In its type section, the Skillogalee Dolomite is overlain by laminated grey siltstones and shales of the Woolshed Flat Shale. Laterally, it passes into the Woolshed Flat Shale to the southeast.

Proposed formations

NATHALTEE FORMATION

The *Nathaltee Formation*, after Nathaltee Creek 30 km northeast of Port Augusta, applies to the "silty-quartzitic sequence containing light grey or cream dolomite beds" mapped by Binks (1971) in the southern Flinders Ranges as the lower part of the Skillogalee Dolomite. The Depot Creek area (30 km northeast of Port Augusta), described by Preiss (1973), has been selected as the type area for the Nathaltee Formation. The type section is located 1 km south of Depot Creek (Fig. 2A) and was preferred to that in Depot Creek because of the influence of minor diapiric breccia in the latter section. The transitional contact with the underlying Emeroo Quartzite is marked by the introduction of dolomites and siltstones into the sandstone dominated sequence at the top of the Emeroo Quartzite. Interbedded sandstones continue into the lower part of the Nathaltee Formation, which is divisible into three informal units totalling 135 m thick (Fig. 3).

Unit 1. This basal unit is dominated by grey coloured lithologies, although the lower few metres are characterised by cross-cutting red oxidation zones. It consists of about two-thirds carbonate facies and one-third terrigenous clastics. The carbonate facies are dominated by grey and dark-grey laminated dolomicrites with pale-grey to black chert nodules. The dolomite has recrystallized to microspar, but the sediments clearly originated as mudstones (in the sense of Dunham 1962). Desiccation cracks and small scale soft sediment deformation structures are present. Limited penecontemporaneous erosion of lithified dolomicrites formed interbeds of intraformational dolomite conglomerate. Stromatolites, which occur as both columnar and domal forms, are similar petrologically to the laminated dolomicrites, and also contain irregular black chert nodules. Intraformational magnesite conglomerates are of limited occurrence in this unit.

Terrigenous clastics are represented by sandstones and siltstones, the abundance of which may vary between the type section and the surrounding area. Sandstones may have either quartzose or dolomitic cements, and are subarkosic in composition. Grain size ranges from fine- to coarse-grained sand, and sorting is moderate. Planar bedding and lamination are the dominant sedimentary structures, but symmetrical wave ripple marks and desiccation cracks may occur in outcrops adjacent to the type section. Interbedded siltstones, partly dolomitic, are planar and wavy laminated. These clastic sediments occur as thin interbeds within dolomites, or as thicker beds up to 6 m thick.

Unit 2. Unit 1 is gradational into a sequence of light-grey and buff dolomites, and grey-green siltstones. The latter, forming in excess of

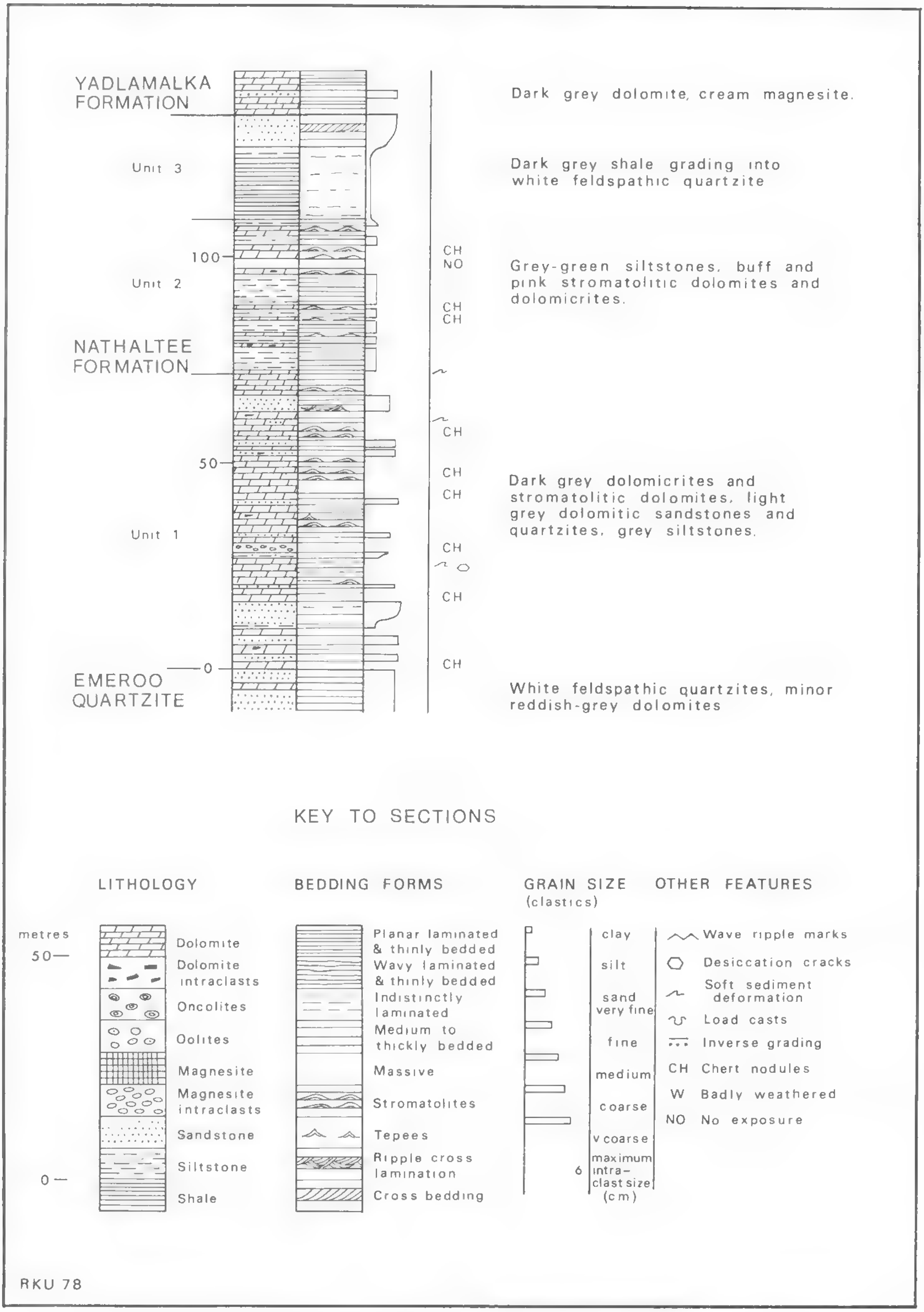


Fig. 3. Type section of the Nathaltee Formation and key to sections in Figs 3, 4, 5 and 7.

50% of the outcrop, are well laminated, but other sedimentary structures apart from occasional desiccation cracks, are absent. Dolomites are dominantly stromatolitic (Figs. 3 and 8). The stromatolites, described by Preiss (1974), exhibit irregular vertical to horizontal columnar growth, and occur in extensive biostromes. Penecontemporaneous erosion of stromatolites is indicated by micro-unconformities within the stromatolite columns (Preiss 1974), and the presence of intraclasts between columns. Planar laminated dolomicrites are similar to those in Unit 1 but are light-grey in colour. Although terrigenous clastics within this unit are dominantly of silt and clay size, sand was occasionally introduced during erosion of stromatolitic and planar laminated dolomicrites.

Unit 3. Dark-grey, poorly laminated shales comprise the lower part of this unit. They are gradational into siltstones and grey fine-grained sandstones, with clean washed, pale quartzites at the top of the unit. The latter are subarkosic in composition, and contain symmetrical ripple marks and tabular cross beds up to 2 m thick. This unit forms a marker bed within the Emeroo Range, but lenses out approximately 2 km north of Mundallio Creek.

Distribution of the Nathaltee Formation

Outcrops of the Nathaltee Formation occur in the Emeroo Range, in which the type section occurs, the Port Germein Gorge and Beetaloo Valley areas, and in the Yednalue Anticline north of Orroroo (Figs 1 and 7A). In other areas of outcrop of the Mundallio Subgroup in the southern Flinders Ranges, the Nathaltee Formation is absent (Fig. 7A). The contacts between the sandy sequence of the underlying Bungaree Quartzite, and the overlying Yadlamalka Formation, are transitional. Light coloured dolomites, similar to those present as interbeds within the Bungaree Quartzite, occur in this transition.

In Port Germein Gorge and the Beetaloo Valley, siltstones with interbedded quartzites and dolomites mark the transition from the Emeroo Quartzite to the Nathaltee Formation. This is overlain by a sequence of interbedded green siltstones, buff stromatolitic dolomites and laminated dolomicrites similar to Unit 2 of the type section. A poorly laminated shale overlain by trough cross bedded quartzites, is comparable to Unit 3. There is no magnesite within the formation in this area. In the Yednalue Anticline, darker grey facies including siltstones, sandstones, laminated and stromatolitic dolomites comparable to Unit 1, comprise most of the formation. Rare intraformational magnesite conglomerates occur, and may have been derived from the Yednalue area, 20 km northwest, where laminated magnesite of the Yadlamalka Formation occurs only a short distance above the top of the Yednalue Quartzite (equivalent to the upper part of the Emeroo Quartzite and Aldgate Sandstone).

Depositional Environment of the Nathaltee Formation

The transition from the Emeroo Quartzite and its equivalents to the Nathaltee Formation represents a decrease in the sand supply to the basin of deposition, with silt and clay size material becoming the dominant terrigenous detritus. The depositional environment of the Nathaltee Formation was predominantly one of low energy with only intermittent sand influx. The grey-green colour of the siltstones, and their lack of current formed structures, indicate limited reworking and sufficient organic activity to maintain mildly reducing conditions within the sediment. Subaerial exposure was relatively frequent near the base of the formation, indicating that the environment varied between "intertidal" and "subtidal". These terms are used without the implication of regular diurnal tides, and associated tidal currents. Rather the terms "supratidal", "intertidal" and "subtidal" refer to degrees of subaerial exposure (Laporte 1975). Tidal and other effects may cause fluctuating water levels. However Unit 2 of the type section, and related facies elsewhere, were predominantly subtidal deposits, with only occasional desiccation cracks and rare possible gypsum casts (Fig. 9). Dolomite interbeds are frequently stromatolitic, hence algal activity as well as trapping sediment may have provided favourable micro-environments for the precipitation of carbonate (Schneider 1977, Zamarreño 1977). The irregularity of stromatolite columns (see descriptions in Preiss 1974) and the dominance of wackestone as the interspace sediment (Preiss 1974), indicate that stromatolite growth occurred relatively undisturbed in a low energy subtidal environment. Micro-unconformities within the stromatolite columns (Preiss 1974), and scattered intraclasts between columns, resulted from intermittent wave or current activity, and possibly from the reworking of desiccated algal mats. Variable dolomite colour from dark-grey to buff within the formation is mainly a result of different oxidizing conditions during diagenesis.

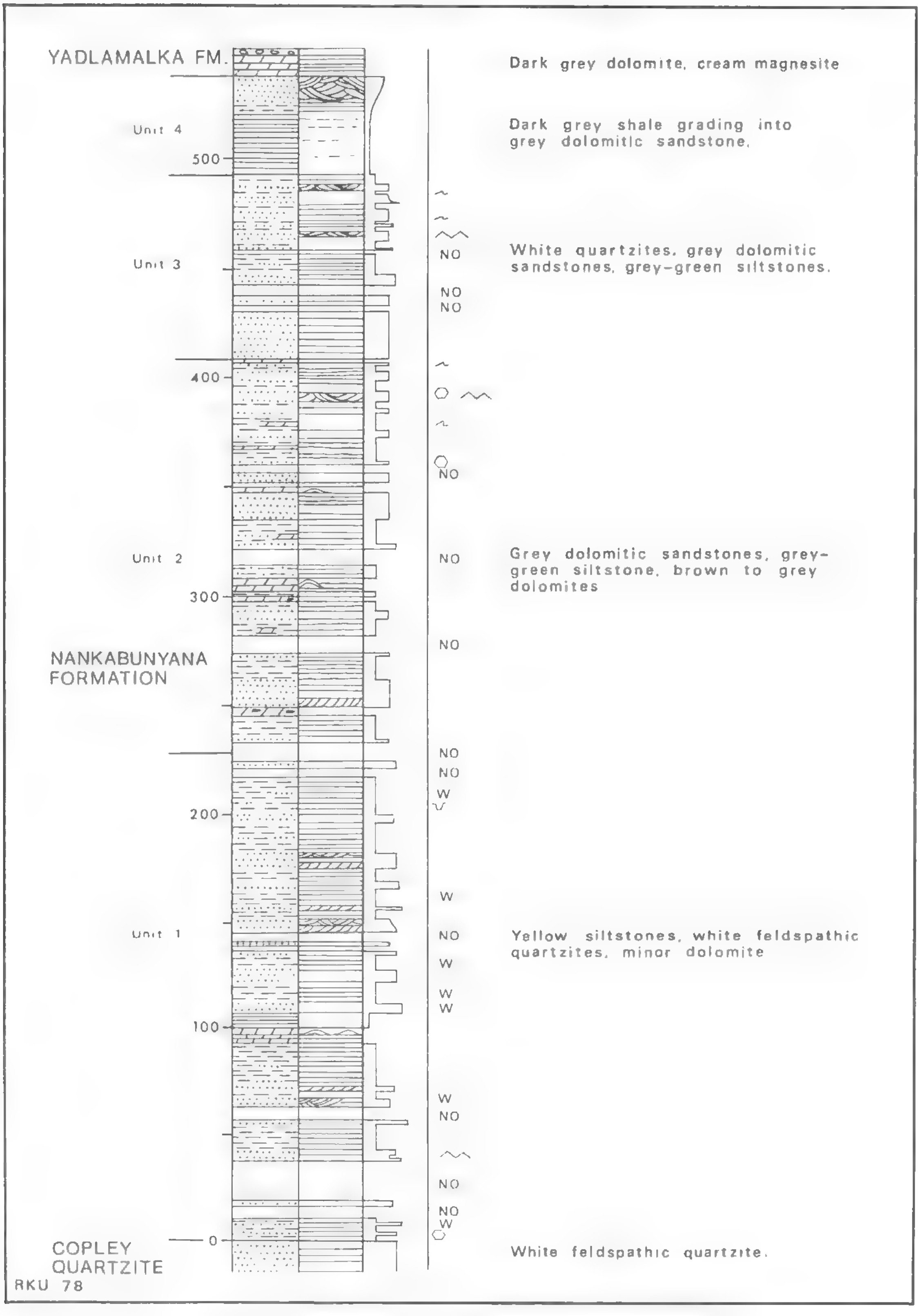


Fig. 4. Type section of the Nankabunyana Formation.

The poorly laminated shale in Unit 3 appears to have been rapidly deposited below wave base. As the depositional environment shallowed, higher energy sands accumulated.

Nankabunyana Formation

The *Nankabunyana Formation*, after Nankabunyana Well, 16 km west of Copley, applies to the mixed clastic-dolomite sequence between the Copley Quartzite and the dolomite-magnesite-sandstone sequence of the Yadlamalka Formation (see below) in the northern Flinders Ranges. This sequence has previously been referred to as the lower unnamed member of the Skillogalee Dolomite (Coats *et al.* 1969). The Nankabunyana Formation is a sequence of interbedded sandstones and siltstones, with minor dolomite interbeds (see below), whereas the Nathaltee Formation, which occurs in the southern Flinders Ranges, consists of interbedded siltstones and dolomites, with minor sandstone interbeds, that were deposited in a lower energy regime (compare Figs 3 and 4). In the type section, 6 km southwest of Copley (Fig. 2B), the Nankabunya Formation is 538 m thick, but thickens northwestward to 715 m at Myrtle Springs. The Formation may be subdivided into four informal units (Fig. 4).

Unit 1. The lower boundary of the Nankabunyana Formation occurs at the top of the last massive quartzite outcrop of the dominantly quartzitic Copley Quartzite. Above this boundary occur poorly outcropping, deeply weathered, yellow siltstones with minor interbedded quartzites. The siltstones are plane-laminated, suggesting that they were deposited from suspension. The interbedded white quartz-cemented feldspathic sandstones, which are fine- to coarse-grained, occur as ripple lenses, and planar bounded units up to 7 m thick. Sedimentary structures include ripple cross-lamination, tabular crossbeds which may have reactivation surfaces, and load casts of sandstone into siltstone. Sandstone-siltstone boundaries are sharp, indicating little intermixing of the finer and coarser components of the sequence. However occasional fining upward cycles occur, and consist of cross-laminated sandstone overlain by interlaminated sandstone and siltstone capped by laminated siltstone (Fig. 10). The only significant dolomite interbed is a brown to pinkish 3.6 m thick dolomicrite overlain by a 2.5 m thick stromatolite bioherm.

Unit 2. The transition to Unit 2 is marked by the introduction of dolomite interbeds, and predominantly dolomite cement in the sandstones. The latter are grey, fine- to very fine-grained, resulting in only small scale current formed structures including symmetrical wave ripple marks and ripple lamination, although planar lamination is more common. Desiccation and synaeresis cracks occur. Interbedded siltstones are greenish-grey, and characterized by a planar to irregular lamination and small-scale soft-sediment deformation features. Interbedded dolomites are lithologically variable and occur as thin interbeds in sandstones and siltstones, and thicker units up to 7 m thick. Buff, brown and grey dolomicrites are most common, but flat-laminated and pseudo-columnar stromatolites (Fig. 11), and intraformational dolomite conglomerates also occur.

Unit 3. A cessation of dolomite deposition and a higher proportion of sandstone than Unit 2, characterize Unit 3. Sandstones are predominantly quartz-cemented rather than dolomite-cemented, and are generally fine-grained, although medium- and coarse-grained interbeds also occur. Planar lamination is abundant, but ripple cross-lamination in sets up to 10 cm thick occurs. Interbedded siltstones are similar to those in Unit 2.

Unit 4. The lower 30 m consists of poorly laminated dark-grey shale which grades upwards into grey dolomitic siltstones and very fine-grained dolomitic sandstones characterized by abundant ripple cross-lamination. The thickness of individual sets increases upwards to a maximum of 15 cm along with the increase in grain size. Unit 4 is a large-scale coarsening upward sequence.

Distribution of the Nankabunyana Formation

The Nankabunyana Formation has similar characteristics along its strike extension between Copley and Myrtle Springs, although the proportion of individual lithologies is variable. A similar sequence occurs in the southwestern Willouran Ranges, where the units present in the type section may be recognized. However shales and siltstones, which may contain rare casts of gypsum rosettes, are more abundant. Dolomite facies are similar in the two areas. The formation is 600 m thick near Top Mount Bore on the southwestern side of the Norwest Fault. Northeast of the Norwest Fault, the Nankabunyana Formation is replaced laterally by a unit of dark-grey poorly

laminated shale with minor lenticular dolomite ("Camel Flat Shale" of Murrell 1977[1]), which is overlain by a sequence of white fine-grained sandstones with minor siltstones and dolomites ("Tilterana Sandstone" of Murrell 1977[1]). The complex facies and thickness changes in this area have been discussed by Murrell as part of a regional study of the Willouran Ranges.

In the Arkaroola region the units present in the type section of the Nankabunyana Formation may be recognized, despite increasing metamorphic grade northwards to amphibolite facies which has resulted in the formation of dolomitic marbles and calc-silicates. Lenticular terrigenous conglomerates are locally developed in Unit 1 south of Arkaroola Village. However Unit 1 becomes thicker and finer-grained northwards, and this is associated with a decrease in dolomite content in Unit 2 indicating a gradual deepening of the depositional environment. Scapolite porphyroblasts (mariolite) become common in siltstones as the metamorphic grade increases northwards. They are preferentially concentrated in the finer laminae, indicating the trapping and concentration of chlorine, possibly from saline pore waters, in certain layers (Hietanen 1967).

Depositional Environments of the Nankabunyana Formation

This formation has similarities with the Nathaltee Formation, although the dolomite content is much lower, and formed in response to related environmental conditions. Deposition of the Copley and Wortupa Quartzites was followed by a lower energy regime in which siltstones and shales accumulated. Sandstones occur as sand sheets and ripple lenses, and indicate the periodic development of higher energy conditions causing winnowing. The lower part of the formation (Unit 1) may contain some features characteristic of tidal environments including fining upward cycles (Fig. 10), reactivation surfaces, wave ripple marks, and ripple cross-lamination (Klein 1971). However in the southern part of the Arkaroola region, the presence of lenticular terrigenous conglomerates, and poorly sorted muddy sandstones and sandy shales which are only slightly winnowed, may indicate some fluvial influence. This sequence passes northward into a better sorted sequence of fine-grained sandstones and siltstones.

Introduction of dolomite deposition in Unit 2 is associated with the development of an environment of low to moderate energy in which evidence of tidal currents is lacking. Small scale ripple lamination and symmetrical ripple marks were formed by wave action which was adequate to winnow mud from the associated fine-to very fine-grained sands. The interbedded siltstones were deposited from suspension and lack current formed structures. Periodic exposure may have been caused by the rate of progradation exceeding the rate of subsidence, although smaller scale effects such as storms and wind-induced tides may cause fluctuations in water level (Laporte 1975). Deposition of dolomicrites occurred in shallow subtidal to intertidal environments. Intraformational dolomite conglomerates were formed during high energy periods, in which dolomite intraclasts were transported into areas of sandstone and siltstone deposition.

YADLAMALKA FORMATION

The *Yadlamalka Formation*, after "Yadlamalka" H.S. 50 km north of Port Augusta, refers to that part of the previously mapped Skillogalee Dolomite characterized by interbedded dark grey dolomite, intraformational magnesite conglomerate and dolomitic sandstone. The 258 m thick type section (Figs 2A and 5) in Depot Creek has excellent exposure, although small-scale faulting has resulted in minor repetition of parts of the sequence.

In the type section, the boundary between the Nathaltee Formation and the Yadlamalka Formation is sharp, occurring at the introduction of dark grey dolomites and intraformational magnesite conglomerates (Fig. 5). However the upper boundary with the Undalya Quartzite equivalent is transitional, and is marked by the termination of magnesite deposition. The Undalya Quartzite equivalent is a sandstone dominated sequence which may contain interbeds of dark grey dolomite near its base.

The Yadlamalka Formation is characterized by rapid vertical facies changes, frequently on a scale of less than 1 m (Fig. 5). A variety of carbonate facies is present although approximately 12% of the formation is composed of terrigenous clastics. Dark-grey laminated dolomicrite forming fissile and more massive outcrops is the dominant carbonate facies, and occurs throughout the formation. The presence of planar to slightly wavy lamination, silty and sandy laminae, occasional graded laminae, and evenly textured microspar, indicate deposition of carbonate mud from suspension, with minor current activity introducing silt and sand. Small

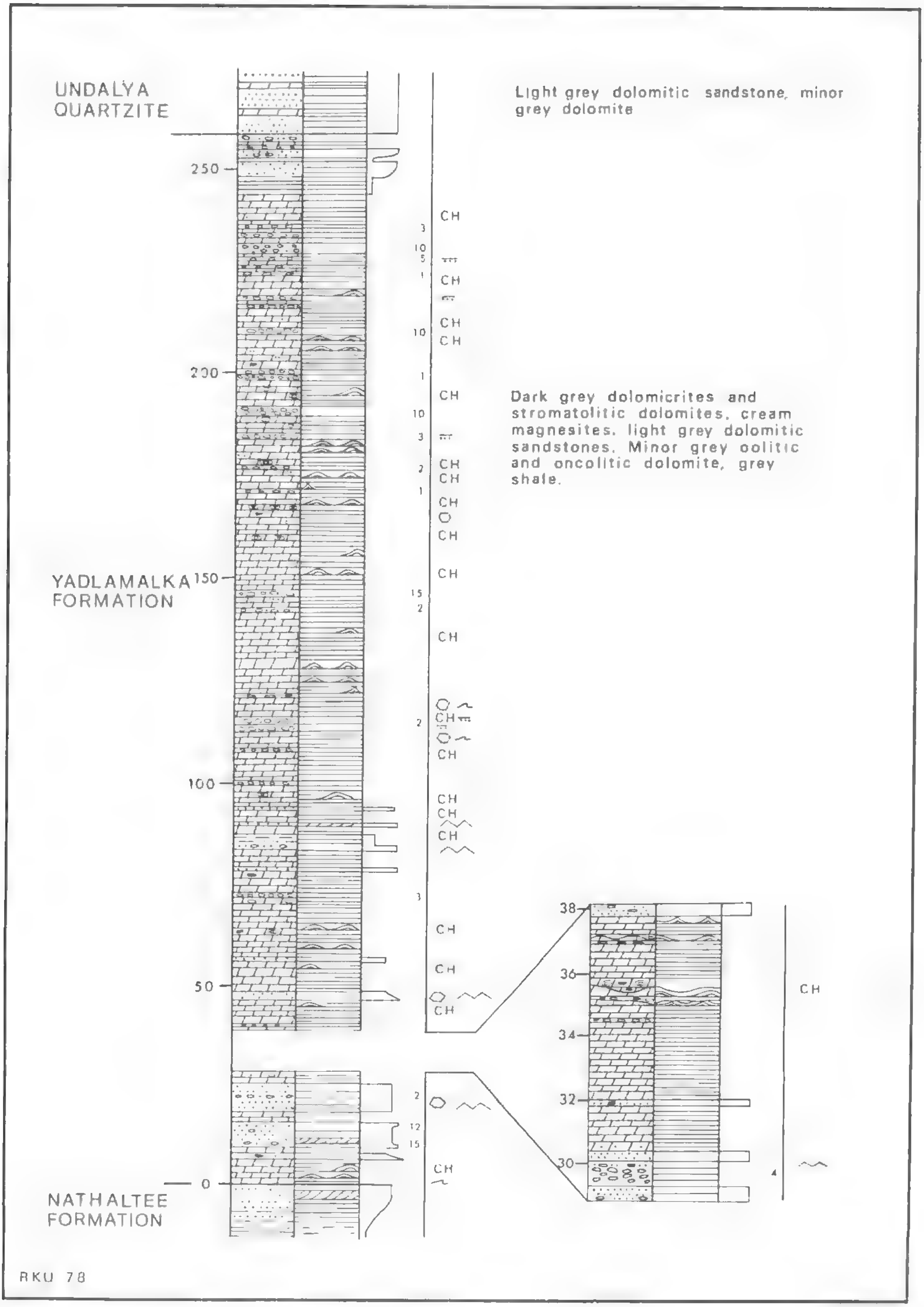


Fig. 5. Type section of the Yadlamalka Formation.

scale slumping and disruption occurred while the sediment was still in a plastic state. Desiccation cracks are relatively common, but tepees are small and rare, indicating that only thin lithified crusts formed during periods of exposure. Secondary silicification prior to and during lithification and compaction, produced lenses and nodules of black chert.

Stromatolites occur in biostromes and bioherms of dark grey dolomicrite, and both columnar and domal forms are present (Fig. 12). The latter may grade into irregularly laminated dolomicrites, representing a gradation from an algal controlled fabric to planar laminated dolomicrites in which the shape of the lamination is not organically controlled. Stromatolites are most abundant in the middle of the formation where the sand content is low.

Grain supported dolomites are minor, and include sandy intraformational dolomite conglomerates, oolitic dolomites and oncolitic dolomites. Oncolites are frequently silicified, and textures of unsilicified oncolites are poorly preserved because of a high proportion of organic matter relative to dolomite in the oncolites, prior to diagenesis. Individual oncolites are either concentrically laminated with asymmetric growth (up to 2 mm in size), or internally massive (up to 1 cm in size). Oncolitic dolomites occur as lenticular beds within dolomicrites, or in more massive beds up to 0.5 m thick which may be associated with stromatolites.

Magnesite, comprising about 11% of the type section, occurs most commonly as intraformational conglomerates, and only rarely as laminated micritic magnesite. Intraformational conglomerates are most abundant in the sandier lowermost and uppermost parts of the formation, and may contain a high proportion of sandy dolomitic matrix, and a maximum intraclast size of several centimetres. Elsewhere intraclasts are frequently close packed with little matrix. Those beds with a higher proportion of matrix are more poorly sorted and may be inverse graded (Fig. 13). This feature may be caused by a high concentration of clasts and matrix in the transporting medium during high energy periods. As a result larger intraclasts move to regions of least shear away from the bed, while smaller intraclasts remain near the sediment interface. Very rapid deposition may preserve this clast size distribution resulting in inversely graded beds (Davies & Walker 1974). Inversely graded beds almost certainly represent a single depositional event such as that resulting from a major storm. Ripple marks and cross bedding occur rarely in finer intraformational conglomerates, and indicate reworking of intraclasts by waves and currents. Laminated micritic magnesite and individual intraclasts of magnesite have a very low content of silt and sand size terrigenous sediment, and their micritic texture indicates that very early diagenentic lithification has inhibited recrystallization.

Interbedded sandstones are most common near the base and top of the formation. Average grain size is fine- to medium-grained sand, and dolomite cement is ubiquitous. However sorting is only moderate, due to the wide range of grain sizes present in individual beds (coarse-grained silt to coarse-grained sand). Petrologically the sandstones are subarkoses, with potassium feldspars more abundant than plagioclase. Sedimentary structures include tabular crossbeds indicating easterly flowing currents, symmetrical wave ripple marks, and desiccation polygons up to 15 cm in size. Siltstones and shales are of minor importance (Fig. 5).

Distribution of the Yadlamalka Formation

The distribution of this formation is shown in Figs 1 and 7. In all areas of occurrence the formation is characterized by facies similar to those described above for the type section. Thicknesses are variable and reach a maximum of 3000 m in the area southwest of Rischbieth Hut in the Willouran Ranges.

In the southern Flinders Ranges between Port Germein Gorge and Yacka very sandy sequences with only minor magnesite occur (Forbes 1960). East of Yacka, on the River Broughton, approximately 57% of the Yadlamalka Formation is dolomitic sandstone, and 10 km to the west carbonate deposition was outweighed by clastic deposition, to such an extent that the Yadlamalka Formation cannot be distinguished from the underlying Bungaree Quartzite and overlying Undalya Quartzite (Fig. 7A). Hence there was a relatively continuous influx of sand into this area during deposition of the Yadlamalka Formation. However in the Depot Creek area, this influx was significant only near the base and top of the formation. In the more easterly sections in the centre of the ORROROO 1:250 000 map sheet, the sandstone content is generally low, and dark grey dolomicrite is the dominant lithology. The percentage of magnesite is low in the southern Flinders Ranges, apart from

the Depot Creek area (11%), and north of "Yednalue" H.S. (5%).

Outcrops in the northern Flinders Ranges may contain a higher proportion of magnesite, dominantly as intraformational conglomerates. The maximum occurrence is southwest of Copley (Forbes 1960) where 18% of the formation is intraformational magnesite conglomerate, and 3% is laminated micritic magnesite. This may be attributed to very low depositional slopes resulting in broad areas of magnesite deposition on the basin margin. These areas were subjected to extensive penecontemporaneous erosion. A 60% increase in thickness of the Yadlamalka Formation occurs between Copley and Myrtle Springs, with virtually no facies changes. Hence depositional rates matched differential subsidence because of favourable conditions for carbonate deposition. A shallow water environment with virtually no depositional slope was maintained.

Dark-grey dolomicrites, and grey very fine-grained sandstones, are the other major lithologies in the Copley area and, along with magnesite, also dominate outcrops of the Yadlamalka Formation in the Arkaroola region. In the southwestern Willouran Ranges, the interval equivalent to the Yadlamalka Formation, has been designated the "Cadnawitana Formation" by Murrell (1977)[1]. However because similar facies are present in this region, in the remainder of the northern Flinders Ranges, and in the type section of the Yadlamalka Formation, this formation may also be used in the southwestern Willouran Ranges. However in this area the clastic content increases, and the magnesite content decreases, in a northeasterly direction, and the Yadlamalka Formation is replaced laterally by the "Mirra Formation" (Murrell 1977[1]). This formation is characterized by more than 50% terrigenous sediment (sandstone, siltstone and shale), and negligible magnesite. The facies relationships within this area, and the often dramatic thickness changes, have been well documented by Murrell.

Depositional Environments of the Yadlamalka Formation

It is apparent from Fig. 5 that the Yadlamalka Formation contains frequent and abrupt vertical facies changes, a characteristic in all its areas of occurrence. Lateral changes may be less significant because of small depositional slopes (Preiss 1973). Rapid lithological changes are often characteristic of shallow water carbonate sequences (James 1977). Deposition of the Yadlamalka Formation occurred in a shallow water, predominantly low energy environment, in which tidal effects were likely to be weak or insignificant, because of the presence of a large shallow basin with low gradients. However slight changes in water level caused by the action of wind and storms, progradation due to sediment buildups, or tectonic influences, may have caused vertical facies changes, and periodically exposed extensive areas within the basin.

The most abundant carbonate facies is dark grey dolomicrite. A predominantly subtidal environment of deposition for this facies is indicated by the lack of fenestral fabrics, scattered desiccation cracks, and the limited occurrences of intraformational dolomite conglomerates due to minor development of lithified crusts. Tepees are uncommon, and are simple structures a few centimetres in size, indicating that extended periods of exposure of this facies did not occur (Assereto & Kendall 1977).

The occurrence and distribution of stromatolitic dolomites within the Yadlamalka Formation have been described by Preiss (1973), and this facies often represents less than 1% of its total thickness. Extensive biostromes are the most frequent mode of occurrence, and formed in low energy subtidal environments. Inter-column sediments may be sandy and intraclastic, indicating that higher energy events may have accompanied stromatolite growth. However the biostromes are frequently overlain by low energy dolomicrites. Smaller bioherms may be enclosed in higher energy sediments. During deposition of the Yadlamalka Formation, organic activity, probably dominated by blue-green algae, may have been quite abundant, as indicated by carbonaceous material preserved within dark grey dolomicrites. However stromatolites (structures in which algae not only played an active role in trapping and binding sediment, but also controlled the shape of the lamination and produced structures with relief) are of much less importance than planar laminated dolomicrites in which algae played a passive role. Hence it would appear that environmental factors, e.g. the rate of sediment influx and the amount of turbulence, as well as chemical and biological factors, were in general unsuitable for stromatolite growth. In addition, conditions may not have been favourable for penecontemporaneous cementation and preservation of stromatolites.

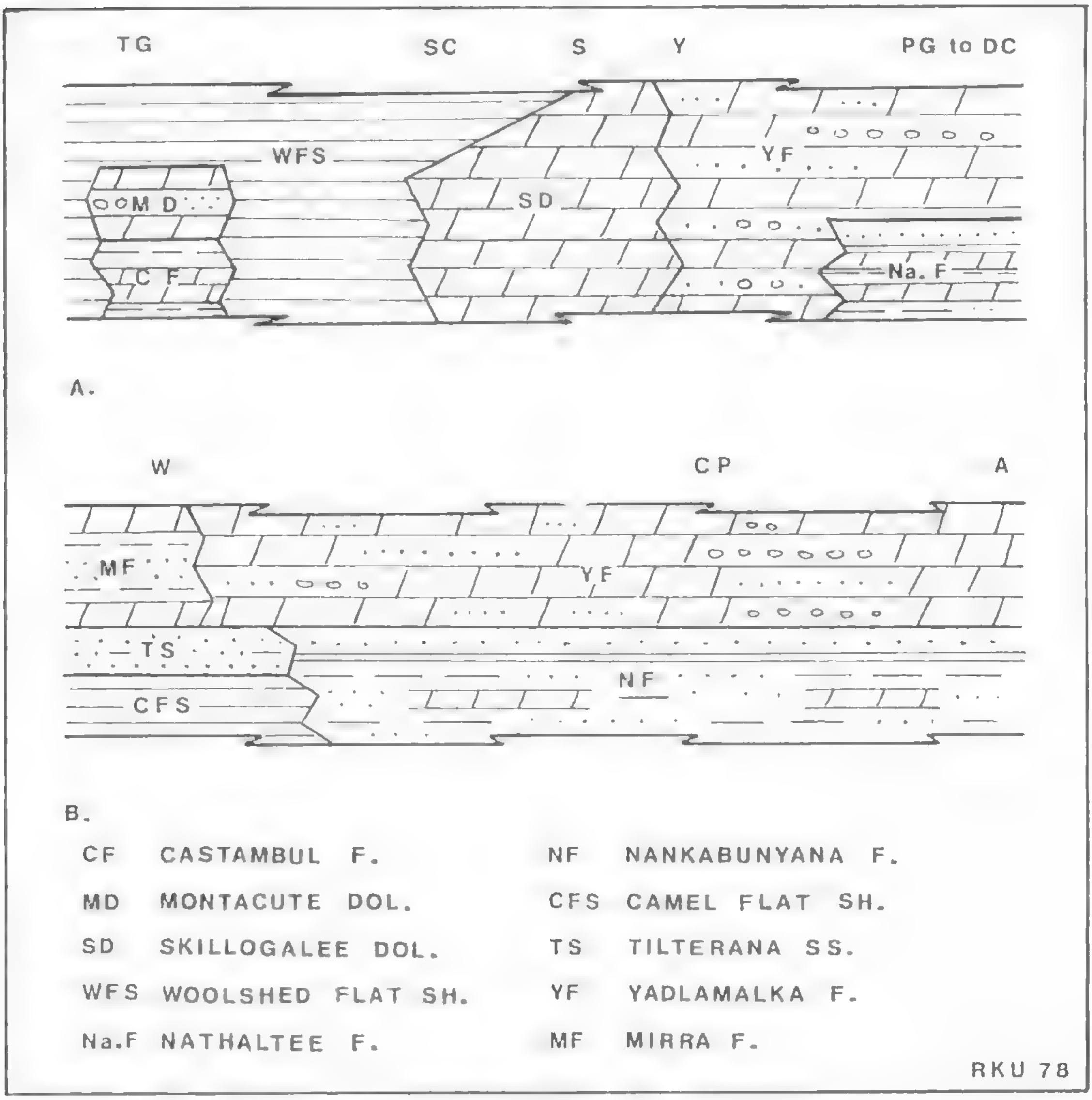


Fig. 6. Rock relation diagrams for the Mundallio Subgroup. Locations as in Fig. 1. and lithological symbols as in Fig. 3.
A. Mount Lofty and southern Flinders Ranges.
B. Northern Flinders and Willouran Ranges.

Micritic magnesite formed in low energy environments on marginal shelves and restricted lagoons. The absence of stromatolites indicates that these environments were unfavourable for persistent organic activity. The magnesite was subjected to extended periods of exposure during which tepees and lithified crusts formed. Erosion of these crusts resulted in deposition of intraformational magnesite conglomerates in a range of environments from marginal magnesite lagoons to subtidal dolomite environments. Low depositional slopes produced sheet conglomerates rather than channel based beds. The presence of dolomite as a matrix in intraformational magnesite conglomerates, and the rare occurrence of interlaminated dolomite and magnesite, indicate that these two minerals formed from different precursors and virtually penecontemporaneously with deposition.

Interbeds of terrigenous sediment are dominantly coarse-grained siltstones, and sandstones. The abundance of interbedded sandstones is dominantly a function of proximity to source, but would also have been influenced by

the prevailing hydraulic regime. Medium- to coarse-grained sandstones are plane-bedded with minor symmetrical ripple marks and tabular crossbeds, while finer sandstones and coarse siltstones contain planar and wave ripple cross-lamination. This association of sedimentary structures indicates that wave action was the dominant process in depositing these sandstones (Reineck & Singh 1973).

Much of the above discussion is also applicable to the Montacute Dolomite which contains similar facies to the Yadlamalka Formation. However the Montacute Dolomite is a much more localized formation and contains more rapid lateral facies changes than the Yadlamalka Formation.

Brief regional synthesis

The distribution and relationships between the formations of the Mundallio Subgroup are indicated in Figs 1, 6 and 7. The formations which are proposed are lithostratigraphic units, and their boundaries are likely to be time transgressive. The boundaries of the Mundallio Subgroup are generally well defined, especially on the western margin of the Mt Lofty and southern Flinders Ranges, where the subgroup occurs between two distinctive sandstone dominated sequences. Well defined boundaries also occur in the northern Flinders Ranges, and in most of the Willouran Ranges, where the Mundallio Subgroup is underlain by quartzites, and overlain by a siltstone-sandstone sequence (Myrtle Springs Formation). However lithological similarities between dolomite interbeds within the Bungaree and Yednalue Quartzites, dolomite interbeds within the Nathaltee Formation, and the Skillogalee Dolomite, indicate that the possibility of intertonguing between the Mundallio Subgroup and the underlying quartzites cannot be excluded.

The shallow to very shallow water sediments of the subgroup overlie sandstones of the lower Burra Group. These sandstones were probably more widely distributed than the more regressive Mundallio Subgroup and may have provided a source for sandstones deposited within the Mundallio Subgroup. The lower part of the subgroup contains a wide spectrum of facies. This resulted from variable subsidence and depositional rates allowing the development of sub-basins, with variable water depths and depositional slopes across the basin as a whole. Significant deposition of terrigenous detritus occurred in many areas, and exceeded dolomite deposition. As a result the Nathaltee Formation and the Nankabunyana Formation were deposited in those areas with an open circulation system which supplied detrital sediment. However in other areas which were more protected from the influx of terrigenous sediment and had favourable water chemistry for carbonate deposition, dolomite deposition exceeded that of terrigenous clastics and deposition of the Yadlamalka Formation commenced. This probably occurred in the Mundallio Creek area and in the vicinity of Yednalue. Outcrops of the Skillogalee Dolomite also have a low content of terrigenous material, and were protected from the influx of detritus by deposition on a broad shallow low energy platform. A shallow topographic high extending southwards from Spalding may have provided a physical barrier to detrital influx, and thus explain the rapid facies changes within the Mundallio Subgroup between Yacka and Spalding (Fig. 7A).

Higher in the subgroup, deposition of the Yadlamalka Formation occurred in a shallow basin with similar water depths over large areas, and low depositional slopes. As a result similar facies were deposited throughout much of the Adelaide Geosyncline. Dolomite became the dominant sediment in many areas due to a lack of fine grained terrigenous sediment, and favourable water chemistry. Sandstone interbeds were numerous adjacent to major source areas west of Yacka and Port Germein Gorge, and northeast of the Willouran Ranges (Forbes 1960, 1961). Magnesite was formed in marginal areas protected from detrital influx. Areas of deposition of the Skillogalee Dolomite remained protected from a supply of sand size material, although in adjacent deeper water regions the Woolshed Flat Shale accumulated.

Acknowledgments

The work carried out in this paper is part of a Ph.D. project in the Department of Geology, University of Adelaide. The author wishes to extend her thanks to Dr V. Gostin, Mr B. Murrell and her supervisor Dr B. Daily for reading the manuscript, and to the personnel of the South Australian Department of Mines and Energy, and the South Australian Stratigraphic Nomenclature Subcommittee, Geological Society of Australia, for helpful discussions.

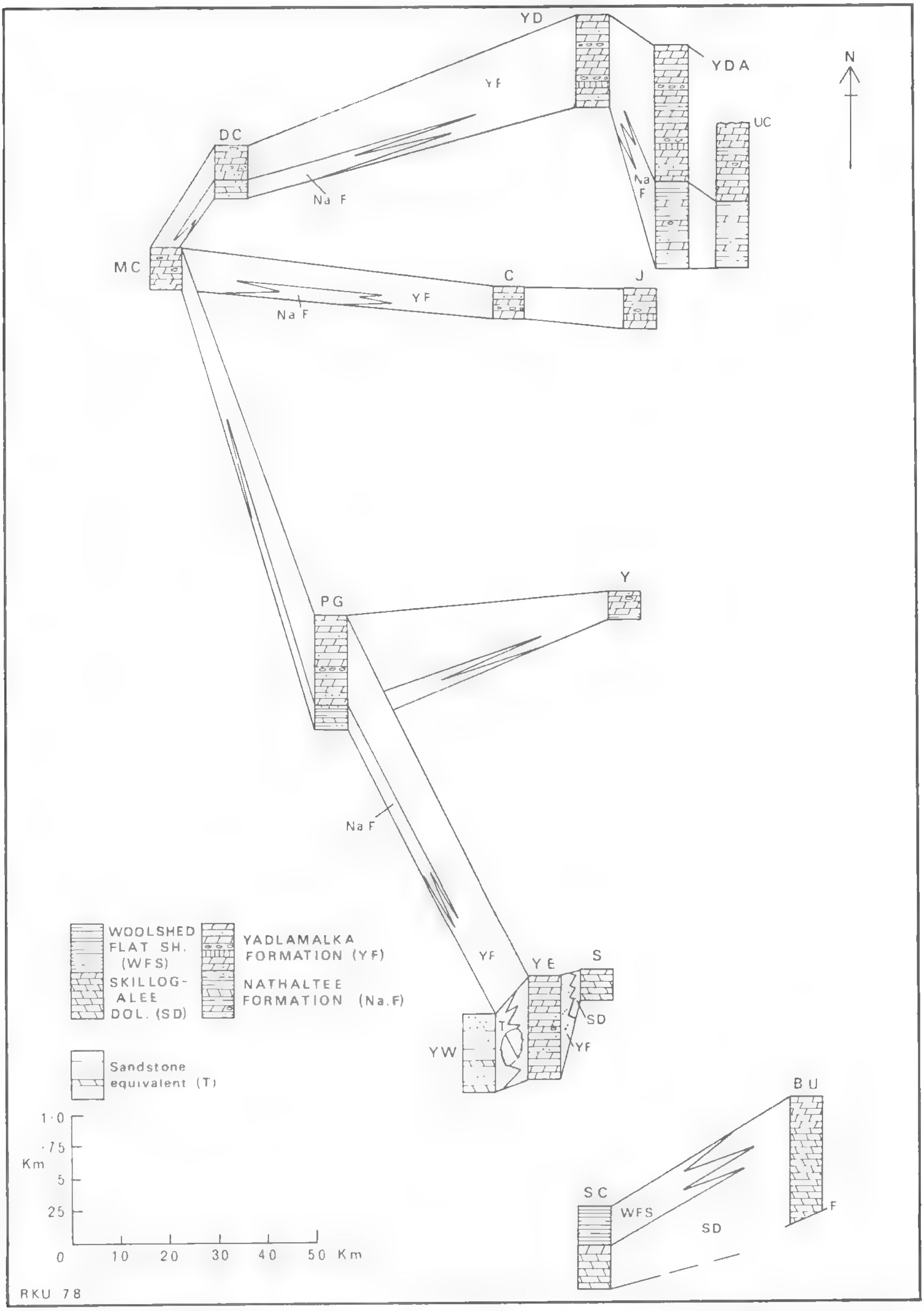


Fig. 7A. Northern Mount Lofty and southern Flinders Ranges—schematic stratigraphic sections and relationships between formations. Locations as in Fig. 1. In addition YW—west of Yacka, YE—east of Yacka.

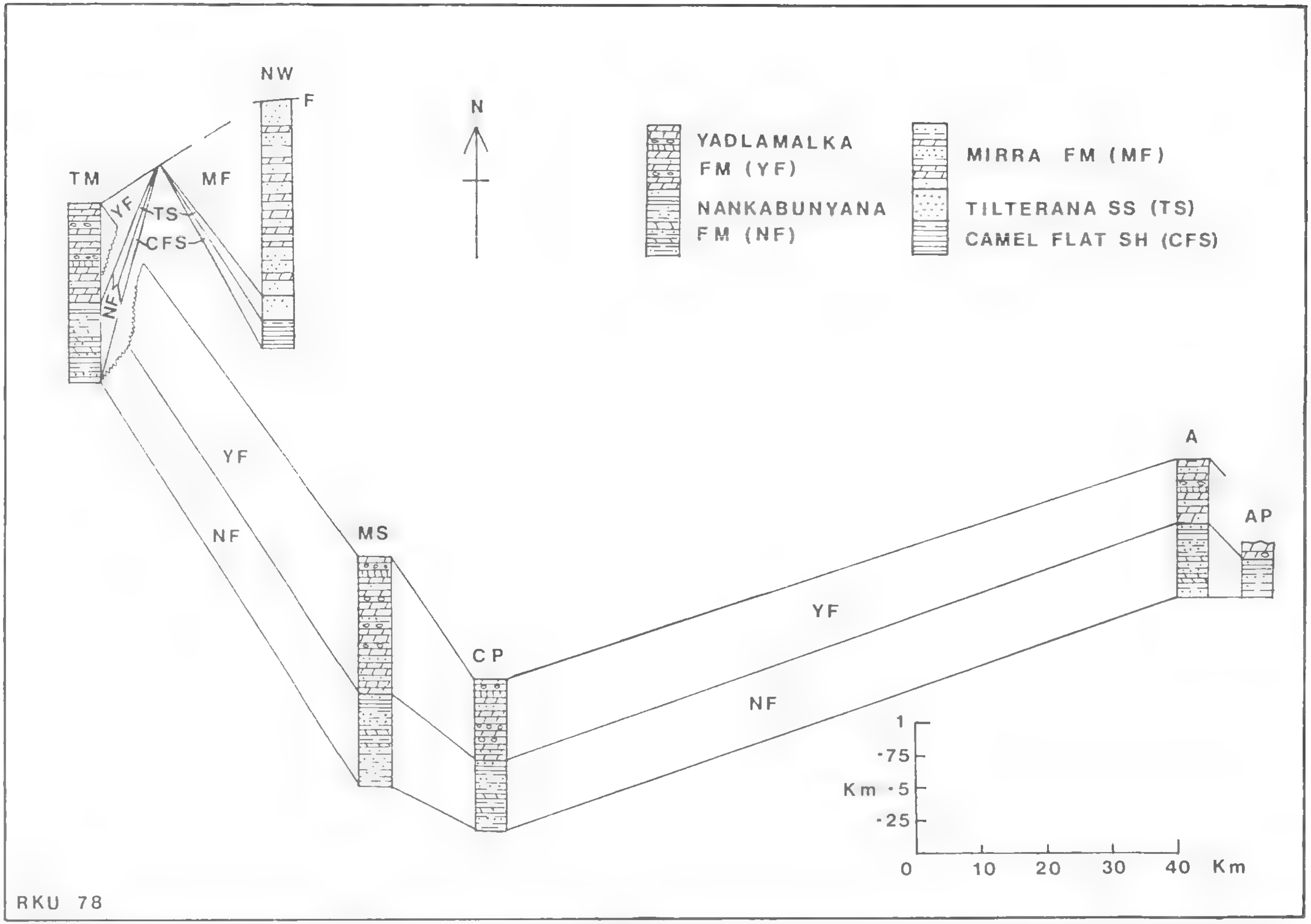
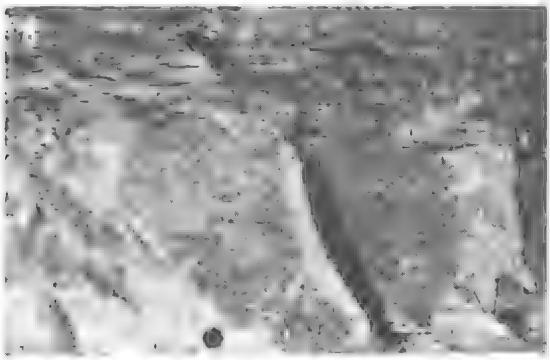
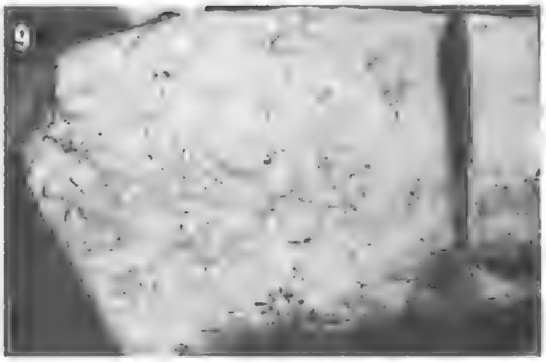
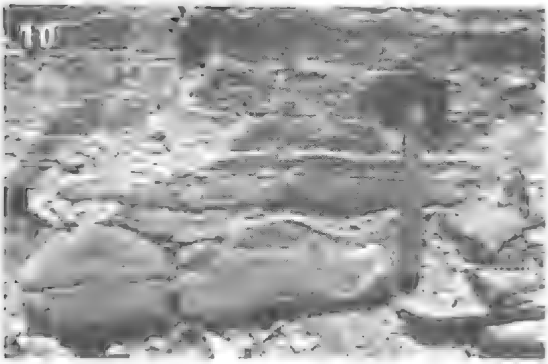
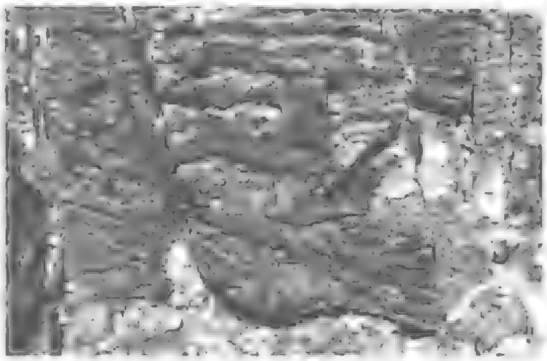


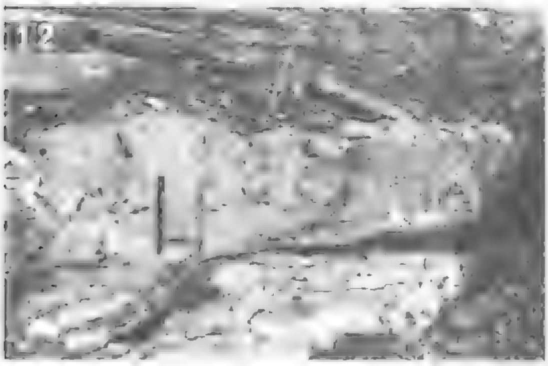
Fig. 7B. Northern Flinders and Willouran Ranges—schematic stratigraphic sections and relationships between formations. Locations as in Fig. 1. In addition: TM—Top Mount Bore. NW—Mt Norwest H.S., M.S.—Myrtle Springs H.S., AP—east of Paralana Fault, Arkaroola.











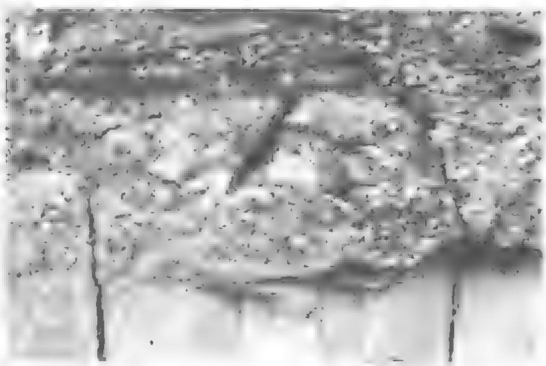


Fig. 8. Domed stromatolite biostrome with poorly defined stromatolites, enclosed in laminated siltstones, Nathaltee Formation, Depot Creek.

Fig. 9. Possibly gypsum casts in siltstones, Nathaltee Formation, Port Germein Gorge.

Fig. 10. Fining upward cycle in which sandstones are overlain by siltstones with sandstone laminae. Unit 1, Nankabunyana Formation, Copley.

Fig. 11. Flat laminated and pseudocolumnar stromatolites with sandy laminae, Unit 2, Nankabunyana Formation, Copley.

Fig. 12 Gently domal stromatolites overlain by planar laminated dolomicrite, Yadlamalka Formation, Depot Creek.

Fig. 13. Inverse graded magnesite intraformational conglomerate with very close packed intraclasts near the base, and a high matrix content at the top, Yadlamalka Formation, south of Depot Creek.

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STRUCTURAL GEOLOGY OF KANMANTOO GROUP METASEDIMENTS BETWEEN WEST BAY AND BREAKNECK RIVER, KANGAROO ISLAND

BY D. J. FLINT & A. E. GRADY

Summary

Kanmantoo Group metasediments cropping out between West Bay and Breakneck River, Kangaroo Island, South Australia, exhibit three phases of deformation. Each phase has developed macroscopic and mesoscopic structures, as well as an axial plane schistosity. The development of these schisosities in one area is unusual for the Kanmantoo Group.

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Kanmantoo Group metasediments cropping out between West Bay and Breakneck River, Kangaroo Island, South Australia, exhibit three phases of deformation. Each phase has developed macroscopic and mesoscopic structures, as well as an axial plane schistosity. The development of three schistosities in one area is unusual for the Kanmantoo Group.

The first folding phase (D_1) produced regional east-west upright horizontal folds with axial plane schistosity, quartz veins and parallel differentiation layering. The second folding phase (D_2) developed abundant mesoscopic upright plunging folds with axial plane fabric elements of schistosity, crenulation cleavace and reoriented transposed bedding. Third phase mesoscopic and macroscopic folding (D_3) has axial plane fabric elements of crenulation cleavage, differentiation layering, schistosity and transposed bedding.

Metamorphism was at a maximum (andalusite-staurolite zone, amphibolite facies) during D_1 folding, and S_1 fabrics are characterised by a high degree of textural equilibrium. Alumina-rich and granitic pegmatites were intruded during D_1 folding. From post-D_1 to syn-D_3, biotite zone (greenschist facies) conditions prevailed but with an increase in textural disequilibrium towards D_3. Retrogression during chlorite zone (greenschist facies) conditions occurred after D_3 folding.

Introduction

Metasediments cropping out between West Bay and Breakneck River in Flinders Chase National Park, Kangaroo Island, South Australia (Flint 1978, Fig. 1) were examined to determine their sedimentary, petrographic and structural history. The metasediments are assigned to the Kanmantoo Group of Cambrian age (Thomson 1975, Daily & Milnes 1971) by lithological correlation with Kanmantoo Group metasediments in their type section. Metamorphism of the Kanmantoo Group in its type section is lower Ordovician (Dasch *et al.* 1971; Milnes *et al.* 1977). Sedimentological aspects and stratigraphic correlations are discussed in Flint (1978), in which the stratigraphic sequence of the West Bay area has been correlated with the Inman Hill Formation of Thomson (1969) and the Tapanappa Formation of Daily & Milnes (1972). This report outlines details of a mesoscopic geometric structural analysis and microscopic textural analysis of the metasediments, exposed in a thin strip of coastline, 20 m wide and 8 km long (Fig. 1).

Rock types exposed are predominantly quartz-rich metasandstones and quartz-mica schists. Rarer types are metalutites, metasandstones rich in heavy minerals, and granitic and alumina-rich pegmatites. Bedding surfaces (S_0) are always recognisable throughout the map area. Rock types and sedimentary structures are involved in cyclic sedimentation units, and are discussed in Flint (1978).

The Kanmantoo Group metasediments exposed in the study area record three deformation or folding phases. Similar results have been obtained from other areas within the Mt Lofty Ranges for Kanmantoo Group and underlying Adelaidean metasediments (Offler

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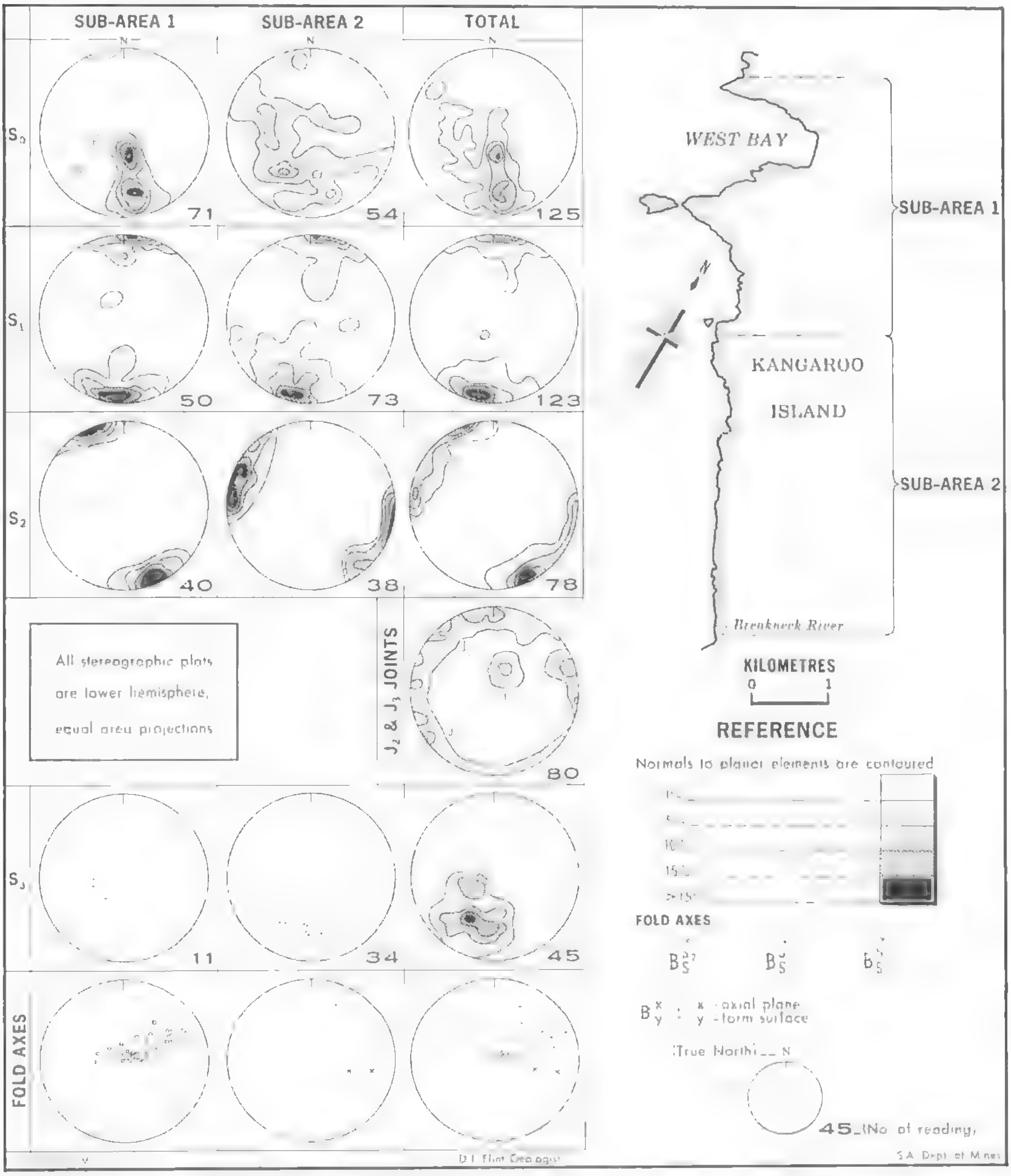


Fig. 1. Structural analysis; stereographic projections and a domain analysis, with extent of outcrop shown.

& Fleming 1968; Mills 1973) but only two phases of folding are recognised in the type section of the Kanmantoo Group between Cape Jervis and Victor Harbor (Daily & Milnes 1971, 1973).

The structural analysis here is based upon abundant and widespread mesoscopic over-printing criteria and the assumption of coherence of orientation of tectonic fabric elements. Different phases can have similar fold styles and axial plane structures. The type of structure developed is a function of:

1. type of sedimentological sequence (sequence 1 and 2 of Flint 1978),

2. position (and hence rock type) within the cyclic sedimentation units.

3. intensity of deformation.

Within a single cyclic sedimentation unit of either sequence 1 or sequence 2 type, the type of structure for a particular phase changes with changing lithology. The abundance of structures and the apparent intensity of deformation is strongly dependent upon the type of sedimentological sequences. The different types of cyclic sedimentation units are spatially separated (Flint 1978, Fig. 2) and this provides a basis for subdivision of the area into two structural domains (Fig. 1). Tectonic structures are poorly developed in the northern area which is dominated by metasandstones of sequence 2 deposits, while the southern area of sequence 1 metasandstones and metalutites records intense mesoscopic folding. The structural and metamorphic history is discussed in the following sections and summarised in Table 1.

TABLE 1.

Summary of structural and metamorphic events

Folding Phase & Axial Plane	Comments
	Early quartz veining; either prior to or during early D_1 folding. Probably corresponds to onset of metamorphism.
D_1, S_1	Maximum metamorphism: andalusite-staurolite zone, amphibolite facies. Regional folds in bedding but with rare mesoscopic folds. S_1 structures dominantly quartz veins with a parallel planar differentiation layering and schistosity. Displacement of bedding across S_1 quartz veins
D_2, S_2	Lower metamorphic conditions: biotite zone, greenschist facies. In sub-area 1, D_2 folding very minor while S_2 is represented as reoriented transposed bedding. In sub-area 2, abundant mesoscopic folding. Reoriented transposed bedding consistently parallel to S_2 crenulation cleavage and schistosity.
D_3, S_3	Continuing biotite zone, greenschist facies metamorphism. In sub-area 1, D_3 folding minor while transposed bedding and schistosity represent S_3. In sub-area 2, abundant crenulations with D_3 strongly folding earlier structures.
	After D_3 folding, retrogression during declining metamorphic conditions: chlorite zone, greenschist facies.

First folding phase (D_1)

The earliest mesoscopic structures developed are quartz veins in metalutites and these predate first folding phase structures. Lithification prior to the onset of D_1 folding is indicated by the presence of these quartz veins and the good preservation of many sedimentary structures in metasandstones. The pre-S_1 quartz veins now form no distinct orientation pattern because of refolding by three phases of deformation.

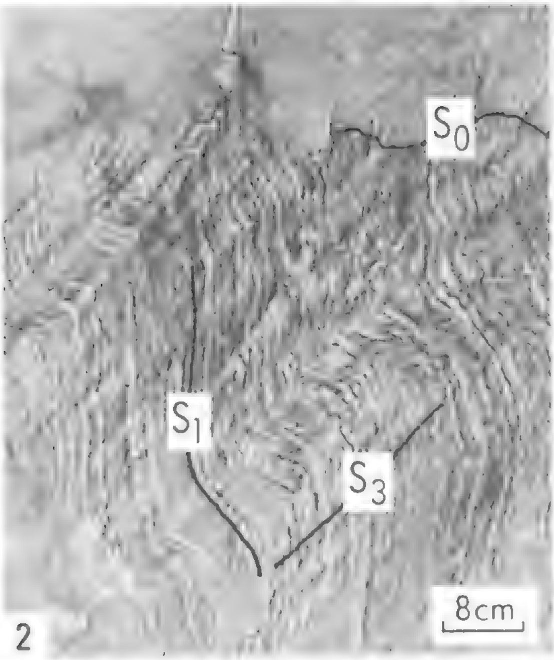
Parallel S_1 fabric elements are schistosity, quartz veins, and a planar differentiation layering which are all considered to be parallel to D_1 axial plane. The S_1 schistosity, where developed, is defined by a perfect biotite and muscovite crystallographic and dimensional preferred orientation; while S_1 differentiation layering consists of alternating quartz-rich and mica-rich layers (Fig. 2). This differentiation layering, which is developed only in quartz-mica schists, is more intensely developed across early (pre-S_1) quartz veins and in rocks of fine grain size (Fig. 3). Often, bedding is displaced across S_1 quartz veins (Fig. 4). Displacement of bedding across planes parallel to the regional first phase axial plane has been observed by Ollier & Fleming (1968) and Daily & Milnes (1973). Although quartz veins are strongly refracted across lithological boundaries and are often extensively folded in lithologies of fine grain size (Fig. 5), in the more massive and mesoscopically homogeneous metasandstones these quartz veins are planar and continuous. Therefore, the orientations of S_1 quartz veins were measured near the base of metasandstones where mesoscopic refolding effects are least evident.

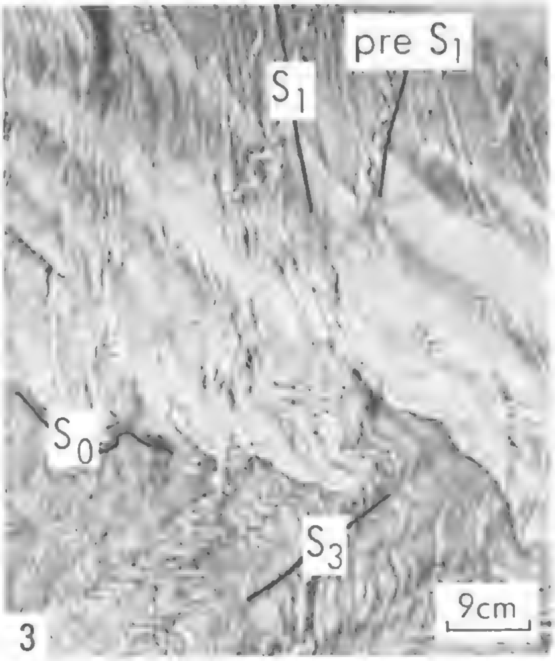
Due to later folding, the D_1 hinge zone trace can only be approximately located within sub-area 2 but a D_1 fold wavelength greater than 6 km is indicated by the regional variation of bedding orientation.

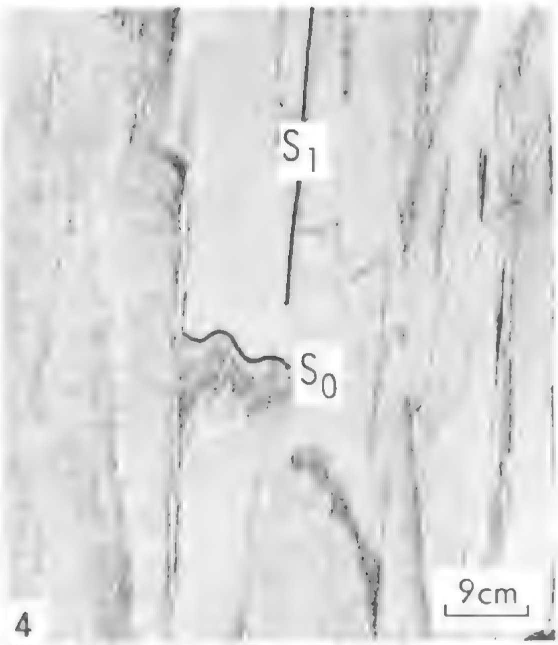
Fold Orientation

S_1 quartz vein, schistosity and differentiation layering orientations are shown together with a domain analysis in Fig. 1. S_1 is used to indicate D_1 axial plane orientation but this cannot be verified by direct observations because folds with S_1 as axial plane are rare.

A great circle distribution of bedding normals in sub-area 1 indicates a macroscopic fold axis plunging horizontally towards 079° (Fig. 1). The average orientation of mesoscopic S_1 planes in sub-area 1 is dipping 86°







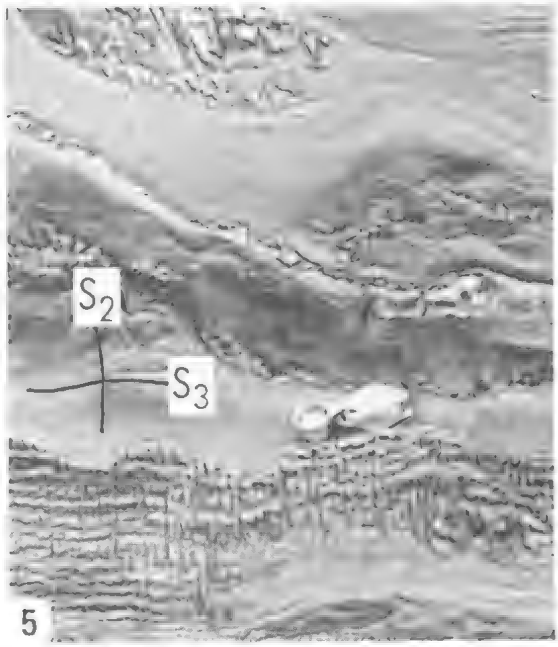


Fig. 2. First phase differentiation layering with some parallel quartz veins. Note strong lithological control on extent of development of the differentiation layering. Contrast with later crenulation differentiation layerings. Minor D_3 folding; sequence 1 deposits, sub-area 2.

Fig. 3. First phase differentation layering (S_1) and its slight enhancement across pre-S_1 quartz veins; sequence 1 deposits, sub-area 2.

Fig. 4. S_1 quartz veins with displacement of bedding. These fault-like planes are parallel to S_1 schistosity and differentiation layering of adjacent rocks; sequence 1 deposits, sub-area 2.

Fig. 5. One S_1 quartz vein which is folded in and out of the exposure surface by D_2 and D_3; sequence 1 deposits, sub-area 2.

towards 010°. The macroscopic fold axis apparently is not contained within the statistical mesoscopic S_1 orientation. The discrepancy suggests that the mesoscopic S_1 as used here may not be parallel with the axial plane of macroscopic D_1 folds. S_1 structures may originate along a plane of maximum resolved shear stress during D_1. Observations over a larger area are necessary to solve the problem.

Although mesoscopic D_1 folds are lacking, observations and interpretations from the map area are consistent with the hypothesis that D_1 folding generally produced the major regional folds throughout the Kanmantoo Group (Ollier & Fleming 1968). Major & Vitols (1973) established that regional folds in Flinders Chase have a northeast to east trend and these are interpreted here as D_1 folds.

Fold Geometry

In sub-area 1 where later folding effects are least evident, D_1 folds are upright horizontal (classification of Rickard 1971) and cylindrical planar (classification of Turner & Weiss 1963). Symmetry of D_1 folds is not determinable on this scale.

Second folding phase (D_2)

Planar features developed during this phase (S_2 structures) are consistently axial plane in orientation to second generation folds in bedding and folds in S_1 structures. S_2 fabric elements are schistosity, quartz veins, reoriented transposed bedding, and crenulation cleavage and differentiation layering. The S_2 schistosity is defined by an imperfect biotite and muscovite crystallographic and dimensional preferred orientation, while the crenulation cleavage is developed from strong microfolding of the S_1 schistosity in metalutites. Where the crenulating is intense, differentiation involving predominantly quartz and mica has occurred to produce a differentiation layering consisting of alternating quartz-rich and mica-rich layers. Identical structures are described in Hobbs *et al.* (1976, Figs. 5.5 and 5.6). S_2 quartz veins are of a different orientation from those produced during D_1 folding, and mesoscopically form the axial planes of folds in S_1 quartz veins and differentiation layering. D_2 folding of bedding (S_0) produced the dominant mesoscopic folds in sub-area 2. D_2 folds in bedding vary in fold wavelength from 5 m to greater than 50 m while folds in S_1 have wavelengths measurable in centimetres. Due to the size of D_2 folds in bedding, few direct measurements could be made of the fold axis.

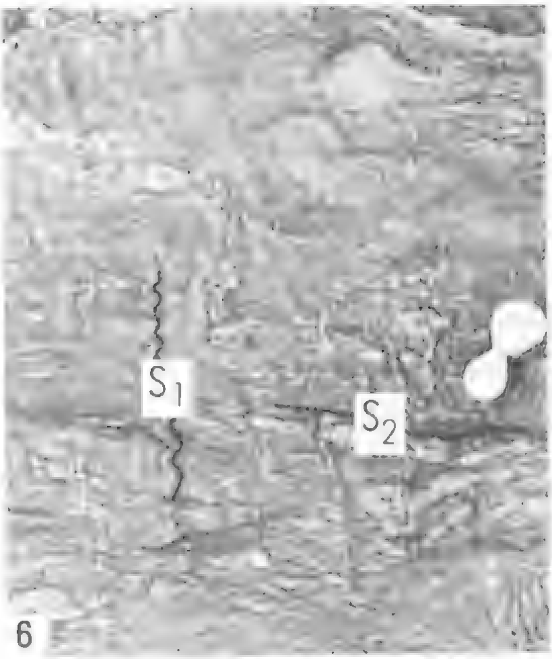
One of the S_2 fabric elements is reoriented transposed bedding but transposition along S_2 during D_2 cannot be proven. The transposed bedding consists of quartz-rich metasandstone blebs consistently elongated parallel to S_2 in a quartz-biotite metasandstone (Figs 6 and 7). Cross-cutting S_1 quartz veins are slightly folded by D_2 with S_2 reoriented transposed bedding as axial plane. S_1 is not disrupted, yet a high state of transposition of bedding parallel to S_2 exists and consistent overprinting relationships unambiguously suggest S_2 post-dates S_1. S_2 reoriented transposed bedding only occurs in units interpreted to have been deposited from mass flows with rapid fallout from suspension (Flint 1978), and the transposed bedding is concluded to be equivalent to a slump breccia and to have formed synchronously with sedimentation. Later reorientation of the clasts occurred during D_2 to produce their present elongation in S_2.

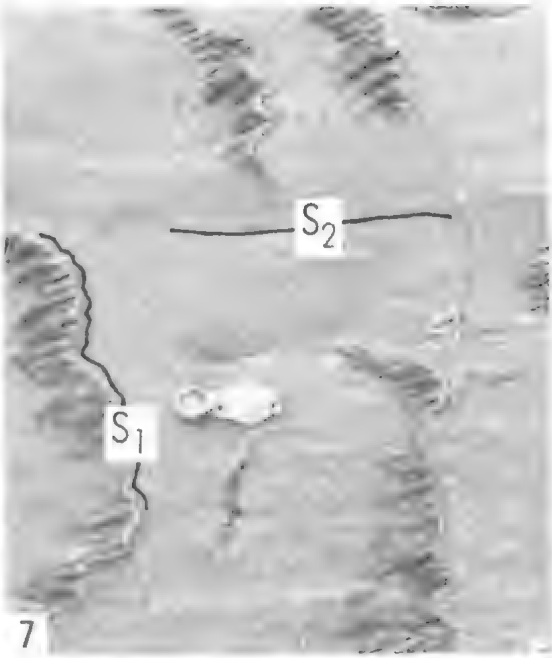
Fold Orientation

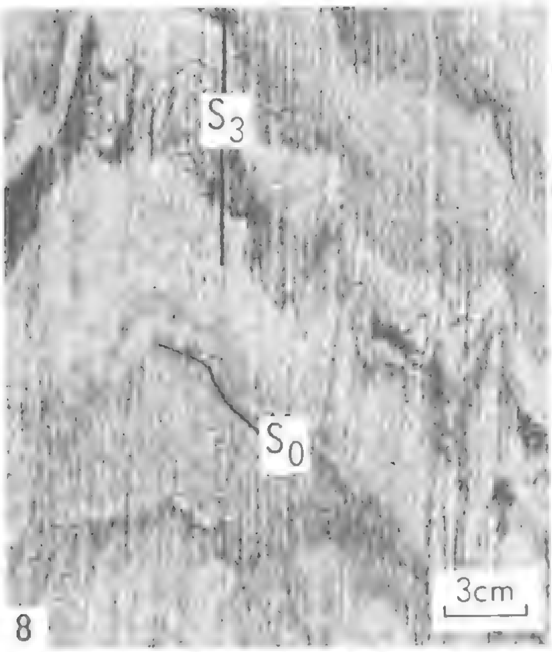
Figure 1 shows S_2 orientation with a domain analysis. D_2 folds are upright plunging with plunges less than 35°. These folds are most strongly developed in the vicinity of the D_1 regional anticlinal hinge zone, i.e. sub-area 2, which results in the shallow plunges. S_2 planes show a systematic variation in orientation from striking 065° in sub-area 1, to striking 000° near Breakneck River (Fig. 14). Either, second phase folds developed as non-planar non-cylindrical folds by asymmetric triclinic strain, or, there has been redistribution of S_2 by a D_3 phase.

In sub-area 1, D_3 folding features are generally not evident. The strong statistical orientation of S_2 (dipping 86° towards 335°) and apparent lack of folding by a D_3 phase suggest that the attitude of S_2 has not been reoriented. Only in the southernmost part of the sub-area is bedding folded by D_2. For these folds, the fold axis plunges 25° towards 065° (Fig. 1). With constant axial plane and fold axis orientation in sub-area 1, D_2 deformation phase produced planar cylindrical and upright plunging folds.

Sub-area 2 is characterised by abundant mesoscopic D_2 folds and the distribution pattern of S_2 structures is consistent with later folding by a D_3 folding phase. Regional D_2 folds are now non-cylindrical non-planar but with an approximately cylindrical axial surface.







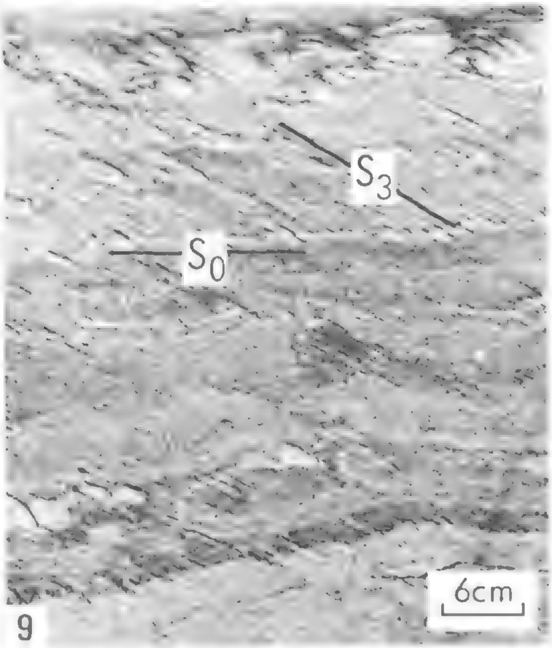
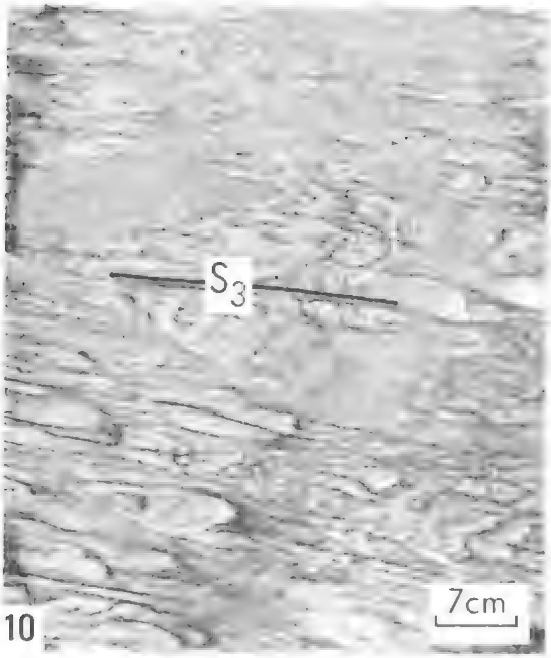


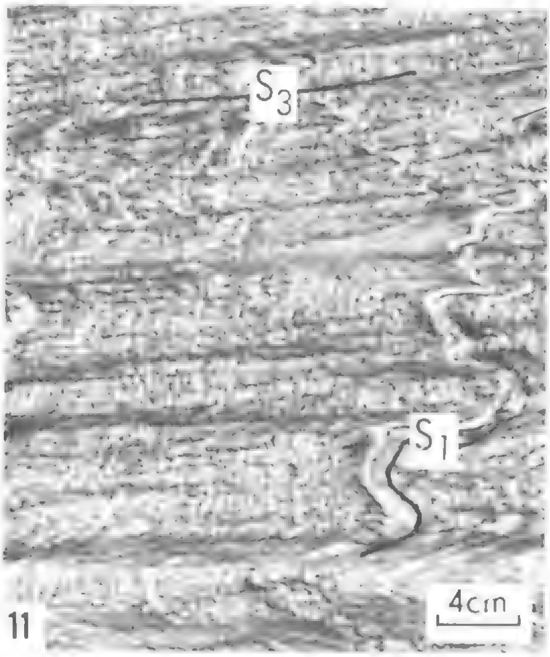
Fig. 6. Reoriented transposed bedding (S_2) which is axial plane to folds in S_1 quartz veins. Note strong transposition parallel to S_2 but only weak folding of S_1; sequence 1 deposits, sub-area 2.

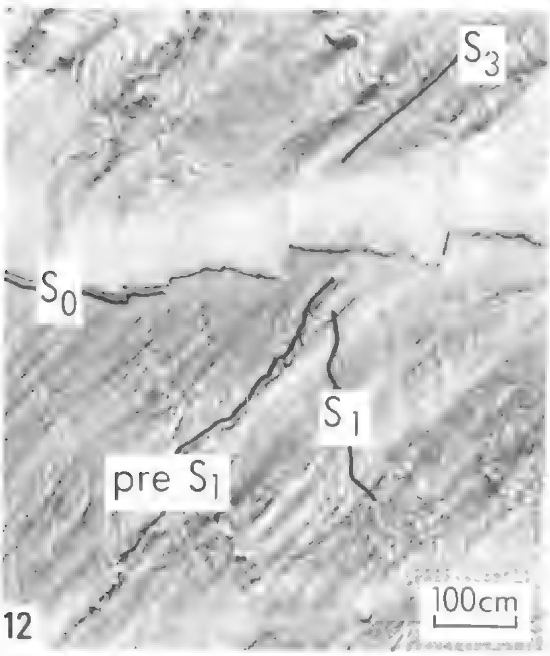
Fig. 7. Reoriented transposed bedding (S_2) which is axial plane to folded S_1 quartz veins; sequence 1 deposits, sub-area 2.

Fig. 8. S_3 schistosity from within the transitional pelitic lutite deposits north of West Bay (sub-area 1). S_3 schistosity rarely developed but where present, is defined by a good preferred orientation of biotite and muscovite.

Fig. 9. S_3 schistosity from within the transitional pelitic lutite deposits north of West Bay. Despite strong microscopic development of the schistosity, mesoscopic D_3 folding is absent.







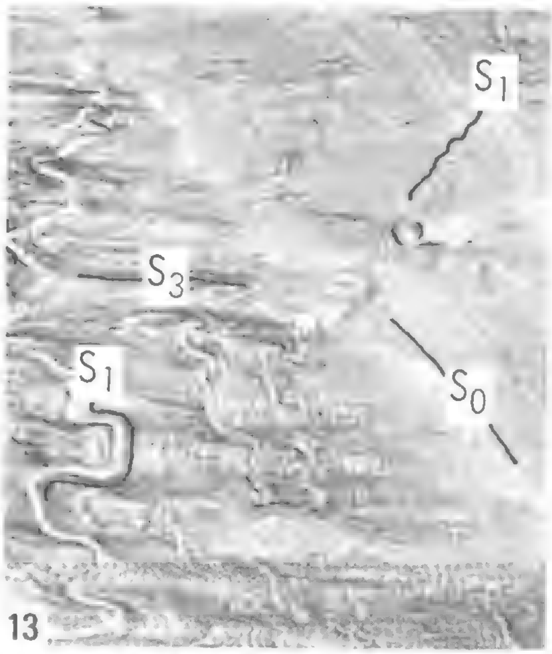


Fig. 10. S_3 reoriented transposed bedding; sequence 1 deposits, sub-area 1. S_3 planes are parallel to S_3 schistosity in adjacent rocks, and to the crenulation cleavage in sub-area 2.

Fig. 11. S_3 crenulation of the S_1 schistosity and parallel quartz veins; initial development stages of a crenulation differentiation layering. Most common S_3 structures for sub-area 2 (sequence 1 deposits).

Fig. 12. Horizontal bedding (S_0) displaced by S_1 quartz veins and parallel differentiation layering. S_1 is folded by S_3 except in the massive metasandstone. Pre-S_1 quartz veins subparallel to S_3; sequence 1 deposits, sub-area 2.

Fig. 13. Strong D_3 crenulating folding of the S_1 schistosity and parallel differentiation layering. Note strong compositional control to deformational response; sequence 1 deposits, sub-area 2.

Joints

Three joints sets are recognised (Fig. 1). Two of these (J_2 joints) are always parallel to the local S_2 orientation or perpendicular to it, i.e. 'ab' and 'ac' joints (Price 1966). As expected, J_2 joints show a similar redistribution pattern to S_2 structures.

Third folding phase (D_3)

In sub-area 1, D_3 structures are intensely developed only within the transitional pelitic lutite sequence north of West Bay (Flint 1978, Fig. 2), while they are almost absent in the sequence 2 metasandstones. The third phase planar fabric elements are schistosity, transposed bedding and strongly deformed sedimentary structures. The S_3 schistosity, where present, is defined by a well-developed preferred orientation of muscovite and biotite (Figs 8–9). Transposition of bedding and strong flattening of sedimentary structures along S_3 surfaces are common responses to D_3 within the metalutites (Fig. 10). Complete transposition of bedding in some instances has produced a fabric which has the appearance of an imbricated intraclastic conglomerate but with a planar fabric element parallel to S_3 planes in adjacent rocks. These S_3 planes have the same orientation as S_3 crenulations in sub-area 2. Macroscopic folding of earlier structures during D_3 is not evident.

In sub-area 2, the most common S_3 structures are crenulation cleavage and differentiation layering, which are axial plane to folded S_0, S_1 and S_2 structures. The crenulation cleavage is developed from microfolding of the S_1 schistosity while the differentiation layering occurs from quartz and mica segregation during intense crenulating folding (Fig. 11). Mesoscopic D_3 folding and refolding is only apparent in the upper portion of each graded sequence. Consistent overprinting criteria and the constant orientation of all S_3 structures enable S_3 to be unambiguously distinguished from S_1 and S_2 despite some similarities in style. Typical mesoscopic relationships between the structures are shown on figures 12 and 13.

Fold Orientation

A domain analysis of S_3 structures (Fig. 1) shows slightly varying orientations between the sub-areas. The average orientation is dipping 45° towards 035°.

Near Breakneck River in sub-area 2, S_1 structures show an orientation variation which suggests folding of S_1 about a sub-horizontal east-west axis. The intersection of S_1 and S_3 in this area plunges 06° towards 095° which reinforces observations of important D_3 folding.

Sub-area 2 contains abundant mesoscopic folds in S_2 structures. The intersection line of the average orientations of S_2 and S_3 plunges 50° towards 019°. Another geometric possibility is the redistribution of S_2 normals along a great circle about a fold axis plunging 60° towards 040°.

The orientation variations of S_1 and S_2 fabric elements in sub-area 2 are consistent with mesoscopic and macroscopic folding during the third deformation phase.

Joints

A joint set (J_3) consistently dips 25° towards 200°, regardless of the orientation of S_0, S_1 and S_2 and is interpreted as a D_3 fabric element.

Domain analysis

The area mapped has been divided into two domains. Subdivision is based upon major sedimentological boundaries, abundance of mesoscopic tectonic folds in bedding, and regionally significant change in S_2 orientation.

Sub-area 1 is comprised predominantly of sequence 2 deposits with metasandstones the dominant lithology; hence few tectonic folds are developed. Deformation features, particularly those of D_3, are most extensively developed in the thin transitional lutite deposit north of West Bay (Flint 1978, Fig. 2). Sub-area 1 is dominated by northward dipping bedding on the northern limb of a regional D_1 anticline (Fig. 14). S_2 structures are of constant orientation but are not important in refolding of S_0 and S_1.

Sub-area 2, comprising of sequence 1 deposits with alternating metasandstones and schists, is characterised by abundant D_2 mesoscopic folds in bedding. S_2 progressively changes orientation from dipping 86° towards 335° in sub-area 1, to dipping 85° towards 090° at the southern boundary of sub-area 2 (Fig. 14). The orientation variation of S_2 with abundant D_3 crenulations in schists indicate the importance of D_3 folding in sub-area 2.

Textures

Recrystallisation of Kanmantoo Group turbidity mass flow deposits (Flint 1978) exposed in this area has produced a variety of textures. Textural terms are as defined by Joplin (1968). Blastopsammitic to lepidoblastic tex-

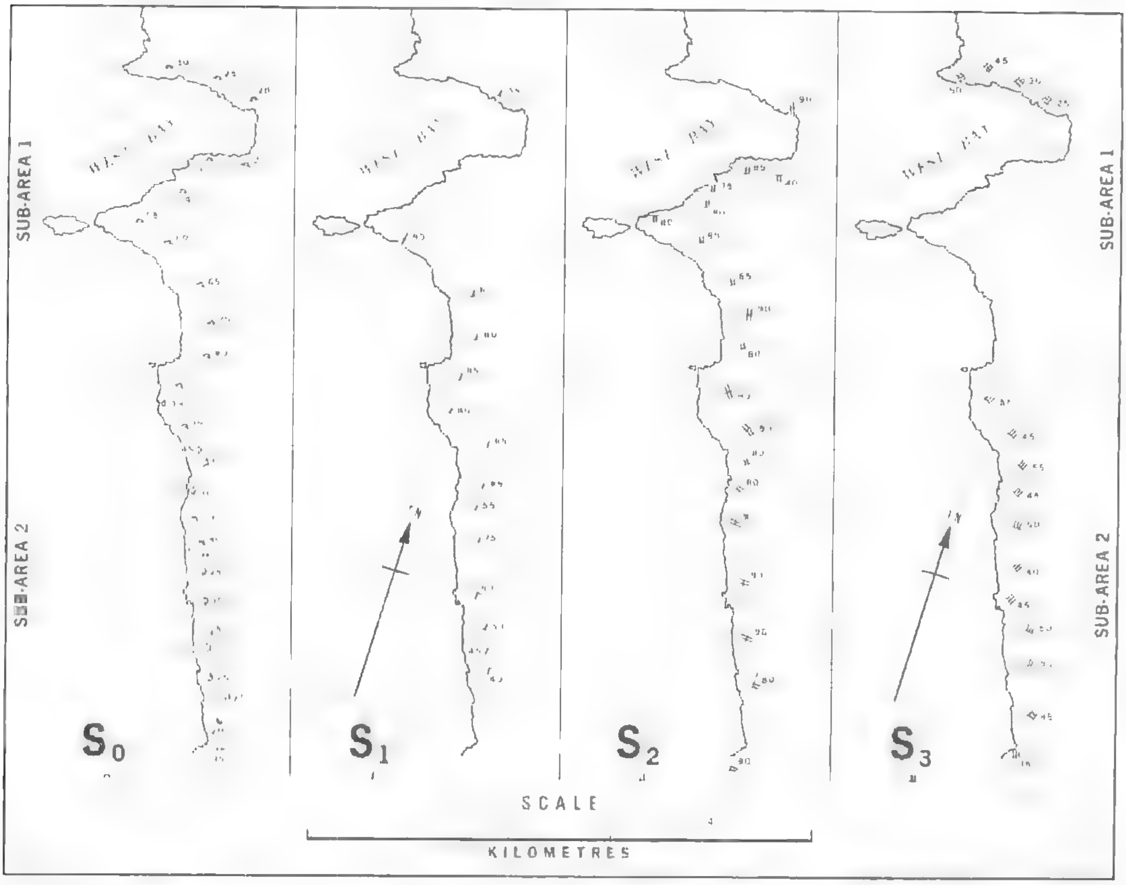


Fig. 14. Representative orientations of bedding planes and axial planes for first, second and third deformations. Note strong orientation variationsin S_0 and S_2 between sub-areas.

tures are common in basal metasandstones of turbidite sequences while schistose textures predominate in metalutites and schists. The variation from blastopsammitic to schistose texture is evident within single turbidite sequences. Small lenticular units of more calcareous composition often exhibit a mortar-like texture. Extensive nucleation and limited grain growth along grain boundaries has produced the apparent cataclastic texture.

Microscopic textural analysis

The crystallisation-deformation relationships have been determined microscopically, using the technique of Spry (1969) to establish changes in grade of metamorphism during the deformation history. Thin sections which form the basis of these observations and interpretations are deposited at the Flinders University of South Australia (numbered 2-7-4 to 2-7-57). Terminology of metamorphic zones (chlorite, biotite and andalusite-staurolite) follows that of Offler & Fleming (1968).

Mineral Growth Synchronous with First-Generation Structures

S_1 schistosity, where developed, is defined by a perfect (001) mica cleavage and dimensional preferred orientation of biotite and muscovite. Textural equilibrium is indicated and chlorite is absent in S_1 schists and structures. Staurolite is developed on the margins of some S_1 quartz veins within sub-area 1. Staurolite poikiloblasts exhibit sigmoidal trains of inclusions with the internal fabric often continuous with the external fabric (S_1), and the S_1 schistosity tends to wrap around the porphyroblasts indicating pre-to syntectonic growth. Staurolite in the absence of chlorite, and textural equilibrium indicate staurolite zone (amphibolite facies) conditions during the D_1 folding.

Aluminous pegmatites containing staurolite, andalusite, sillimanite, margarite, beryl and

tourmaline, together with quartz-feldspar pegmatites are interpreted to have been emplaced during the D_1 folding. Quartz-feldspar pegmatites (containing tourmaline and garnet) are folded disharmonically by D_2 and contain J_2 joints. Near Victor Harbor, pegmatites in Kanmantoo Group sediments are also folded by D_2 (Daily & Milnes 1973). White *et al.* (1967), Dasch *et al.* (1971), and Milnes *et al.* (1977), using field relationships and Rb-Sr dating have shown that granite and pegmatite emplacement in Kanmantoo Group metasediments elsewhere occurred during a high temperature metamorphic and deformation event. As andalusite-staurolite zone conditions are postulated to have been attained only during D_1, it is concluded that the pegmatites in the West Bay area were intruded during the first folding phase. Daily & Milnes (1973) noted development at Victor Harbour of a D_1 schistosity in the margins of the Encounter Bay Granites and boudinaged granite sheets, and concluded that granite intrusion was prior to the culmination of first folding phase in that area.

Mineral Growth post-D_1 and pre-D_2 Folding

The grade of metamorphism during the interkinematic phase appears to be the biotite zone of the greenschist facies. Primary mineralogy of the aluminous pegmatites shows substantial alteration of andalusite to muscovite, fibrolitic sillimanite and margarite (bowtie structures). Sillimanite has nucleated at andalusite-muscovite boundaries and grown perpendicular to andalusite prisms. Although fibrolite is present elsewhere within the Kanmantoo Group, sillimanite without andalusite and staurolite is necessary before classification within the sillimanite zone (Offler & Fleming 1968; Fleming 1973). Muscovite formation from andalusite in the aluminous pegmatites is the prominent feature of post-D_1 to pre-D_2 crystallisation.

Mineral Growth Synchronous with Second Generation Structures

S_1 schistosity is typified by extensive equilibrium textures, perfect alignment of (001) biotite and muscovite (001) and apparently formed under low amphibolite facies conditions. S_2 schistosity textures do not show the same degree of textural equilibrium. S_2 schistosity is defined by an imperfect crystallographic and dimensional preferred orientation of biotite and muscovite. Quartz is more even grained and only slightly elongate parallel to the schistosity. Grain boundaries are often curved and irregular, while 120° triple points and quartz-quartz boundaries perpendicular to mica (001) are quite rare. No D_2 syn-tectonic porphyroblasts are present. Biotite zone (greenschist facies) conditions during the D_2 folding are concluded.

Mineral Growth post-D_2 and pre-D_3 Folding

Porphyroblastic muscovite growth characterises this interkinematic period. Muscovite flakes are either equant or lath-shaped (length to width ratio of less than 3:1) and do not define a dimensional or crystallographic preferred orientation. S_2 schistosity defined by trails of dusty opaques is continuous through the muscovite porphyroblasts while S_2 biotite-quartz schistosity ends abruptly at the edge of muscovite laths. Further muscovite recrystallisation from andalusite, sillimanite and margarite in the aluminous pegmatites is also interpreted.

Mineral Growth Synchronous with Third Generation Structures

D_3 is characterised by the development of crenulation cleavage within sub-area 2 while in the northern portion of sub-area 1, transposed bedding and a schistosity represent S_3 structures. Syn-D_3 porphyroblasts are absent. Large reorientations of S_1 and S_2 schistosities in sub-area 2 are predominantly by crenulating, with limited recrystallisation. In hinge zones of D_3 crenulation folds, quartz-biotite boundaries are noticeably diffuse and gradational, and some micas have curved (001) cleavages. Biotite and muscovite aligned sub-parallel to the crenulation cleavage are rare and have diffuse grain boundaries. Within the northern portion of sub-area 1, a quartz-biotite-muscovite schistosity is associated with transposed bedding.

Lack of chloritisation and any amphibolite facies mineral assemblages, together with a quartz-biotite-muscovite S_3 schistosity within the northern portion of sub-area 1, suggests biotite zone (greenschist facies) conditions during D_3 folding.

Mineral Growth post-D_3 Folding

Chlorite and garnet crystallised after D_3 folding. Garnets are typically pale pink idioblastic porphyroblasts, inclusion-free and superimposed on all schistosities. Earlier formed S_1 staurolite porphyroblasts are often retrogressed to garnet with randomly oriented chlorite. S_1 and S_2 biotites are pseudomorphed by chlorite but only in specimens also containing randomly oriented post-D_3 chlorites. Post-

D_3 is the only recognised period of chloritisation and indicates a lowering of grade from biotite to chlorite zone (greenschist facies). Mortar textures in some quartz-mica metasandstones and calcareous assemblages may result from D_3 or post-D_3 nucleation and limited grain growth.

Discussion

Deformation involving an axial plane schistosity with each of the three significant folding phases in such a small area is unusual. Folding phases D_1–D_2–D_3 of Offler & Fleming (1968) and D_1–D_2 of Daily & Milnes (1973) are correlated with the three deformations in Flinders Chase.

D_1 folding has caused the regional trends in bedding orientation, an interpretation common to many studies on the Kanmantoo Group. Minor macroscopic warping with crenulation cleavage and rare schistosity development usually typifies D_2 and D_3 (Offler & Fleming 1968). In Flinders Chase both D_2 and D_3 macroscopically and mesoscopically fold earlier structures with the development of crenulation cleavages and schistosities. However, Offler & Fleming (1968) report that D_3 axial surfaces are usually steep and have a meridional trend, but near West Bay S_3 has an average orientation dipping 45° towards 035°.

Subdivision of metamorphic grade into chlorite, biotite and andalusite-staurolite zones (Offler & Fleming 1968), is consistent with observed assemblages in Flinders Chase. Mineralogy and apparent petrogenesis is in keeping with low-pressure intermediate facies series metamorphism; a conclusion of Joplin (1968), Offler & Fleming (1968) and Daily & Milnes (1973).

In Flinders Chase, the only amphibolite facies index mineral observed is early- to syn-D_1 staurolite. Pre- to early syn-D_1 cordierite and quartz aggregates have been identified at Victor Harbor (Daily & Milnes 1973). Elsewhere, post-D_1, amphibolite facies mineralogy is commonly observed within the D_1–D_2 inter-kinematic period representing the major development of porphyroblasts (Offler & Fleming 1968). Post-D_1 and pre-D_2 porphyroblasts are completely lacking at West Bay. In general, Offler & Fleming (1968) regard syntectonic porphyroblastic growth as rare but in Flinders Chase, D_1 is associated with porphyroblastic staurolite and maximum grade of metamorphism.

Acknowledgments

This work was supported and funded by the South Australian Department of Mines and Energy and the School of Earth Sciences, Flinders University. The authors benefited from useful comments, suggestions and criticisms by Dr C. D. Branch, Dr M. J. Abbott, Mr R. F. Berry and Mr R. B. Flint.

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VOL. 103, PARTS 3 & 4 31 MAY, 1979

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ROTIFERA RECORDED FROM AUSTRALIA

BY R. J. SHIEL AND W. KOSTE

Summary

Three hundred and thirty-one taxa of Rotifera, in 73 genera, are recorded from Australia. Species names, with published synonymy, are listed alphabetically. Locality records are also given.

ROTIFERA RECORDED FROM AUSTRALIA

by R. J. SHIEL* and W. KOSTE†

Summary

SHIEL, R. J. & KOSTE, W. (1979) Rotifera recorded from Australia. *Trans. R. Soc. S. Aust.* **103**(3), 57-68, 31 May, 1979.

Three hundred and thirty-one taxa of Rotifera, in 73 genera, are recorded from Australia. Species names, with published synonymy, are listed alphabetically. Locality records are also given.

Introduction

Despite increasing interest in Australia's inland water resources, little is known of the ubiquitous rotifer fauna. Since the work of Anderson & Shephard (1892), Colledge (1909–1924), Shephard (1892–1922) and others, the only reports of Rotifera have been species lists from single collections (Russell 1957, 1961; Berzins 1953, 1955, 1963) or individual descriptions (Sudzuki 1975; Sudzuki & Timms 1977). Taxonomic confusion within the group has persisted; no adequate record of the rotifers of Australia is extant.

This paper contributes a list of all species recorded to date from the continent. Recent advances in taxonomy, particularly with the recognition of morphological variability within species (see Koste 1978) has enabled synonymies to be established for many of the early records. Of more than 450 recorded species, 279 are recognized here. A further 52 taxa are recorded for the first time as a result of a survey of the zooplankton of the Murray-Darling system (Shiel 1978, 1979, in press, in prep.[1]; Koste 1979). Varieties are included in the list because in some cases they are the only representatives of the species found to date in Australia.

The format adopted is as follows: valid species names are given in alphabetical order. Frequently occurring synonyms and date of synonymy are given with each valid name, as are locality data and principal references. References citing Rotifera to genus only have been excluded, as have some of the many early works with repetitive listings. *Nomina dubia* and records which are uncertain due to insufficient information, typographical or locality errors are listed separately. Sources of synonymy are: Chengalath (1977), Harring (1913), Koste (1978), Kutikova (1970), Russell (1961), Ruttner-Kolisko (1974), Sudzuki (1964) and Voigt (1956/1957).

Rotifera recorded from Australia

Adineta barbata Janson, 1893
Locality: N.S.W. (Murray 1911).

Adineta gracilis Janson, 1893
Locality: N.S.W. (Murray 1911).

Adineta longicornis Murray, 1906
Locality: N.S.W. (Murray 1911).

Adineta tuberculosa Janson, 1893
Locality: N.S.W. (Murray 1911).

Adineta vaga (Davis) 1873
Locality: N.S.W. (Murray 1911).

Anuraeopsis fissa (Gosse) 1851
1851 *Anuraea fissa* Gosse.
1886 *Anuraea hypelasma* Gosse.
Locality: N.S.W. (Whitelegge 1889), W.A. (Berzins 1953).

Ascomorpha ecaudis (Perty) 1850
1851 *Sacculus viridis* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Ascomorpha ovalis (Carlin) 1943
Locality: N.S.W. (Shiel in prep.).

Asplanchna brightwelli Gosse, 1850
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1911, Russell 1961), S.A. (Shiel, 1978), Vic. (Anderson & Shephard 1892, Shiel 1978), W.A. (Berzins 1953).

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† Ludwig-Brill-Strasse 5, Quakenbrück D-4570, West Germany.

[1]Shiel, R. J. Ecology of the potamoplankton of the Murray-Darling river system. PhD thesis, in preparation.

Asplanchna girodi (De Guerre) 1888
Locality: N.S.W. (Shiel in prep.).

Asplanchna intermedia Hudson, 1886
Locality: Qld (Colledge 1914).

Asplanchna priodonta Gosse, 1850
Locality: N.S.W. (Shiel in prep.), Qld (Russell, 1961), Vic. (Shiel, in prep.).

Asplanchna sieboldi (Leydig) 1854
1883 *Asplanchna ebbesbornii* Hudson.
1889 ?*Asplanchna amphora* Hudson.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Shephard, 1899).

Asplanchnopus hyalinus Harring, 1913
Locality: Vic. (Shiel in prep.).

Asplanchnopus multiceps (Schrank) 1793
1878 *Asplanchna myrmelio* Eyferth.
Locality: N.S.W. (Whitelegge 1889); Qld (Colledge 1914), Vic. (Anderson & Shephard 1899).

Beauchampia crucigera (Dutrochet) 1812
1862 *Cephalosiphon limnias* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914), Vic. (Anderson & Shephard 1892).

Brachionus angularis Gosse, 1851
Locality: S.A. (Shiel 1979), Qld (Colledge 1911), Vic. (Shiel in prep.), W.A. (Berzins 1953).

Brachionus angularis bidens Plate, 1886
1886 *Brachionus bidens* Plate.
Locality: Vic. (Shiel in prep.).

Brachionus baylyi Sudzuki & Timms, 1977
Locality: N.S.W. (Sudzuki 1975).

Brachionus bidentata bidentata Anderson, 1889
Locality: Vic. (Shiel in prep.).

Bracrionus bidentata jirovci Bartos, 1947
Locality: Vic. (Shiel in prep.).

Brachionus bidentata testudinarius Jacubski, 1912
Locality: Vic. (Shiel, in prep.).

Brachionus budapestinensis (Daday) 1885
1894 *Brachionus quadridentatus* Kertesz.
Locality: N.S.W. (Shiel 1979), S.A. (Shiel in press).

Brachionus calyciflorus amphiceros Ehrenberg, 1838
Locality: Qld (Colledge 1911), S.A. (Shiel, 1979).

Brachionus calyciflorus aneuriformis Brehm, 1909
1909 *Brachionus anuraeformis* Brehm.
Locality: S.A. (Shiel in press), Vic. (Shiel, 1979).

Brachionus calyciflorus calyciflorus Pallas, 1766
1838 *Brachionus pala* Ehrenberg.
Locality: N.S.W. (Shiel 1979), S.A. (Shiel in prep.), Qld (Russell 1961), Vic. Shephard 1899, Powling 1979).

Brachionus caudatus Barrois & Daday, 1894
1911 ?*Brachionus lyratus* Shephard.
Locality: Qld (Russell 1961), Vic. (Shephard 1911).

Brachionus dichotomus Shephard, 1911
Locality: Vic. (Shephard 1911), Qld (Shiel, in prep.).

Brachionus diversicornis (Daday) 1883
1883 *Schizocerca diversicornis* Daday.
Locality: S.A. (Shiel in press), Vic. (Powling 1979).

Brachionus falcatus Zacharias, 1898
Locality: Qld (Colledge 1909, 1911; Russell 1961), S.A. (Shiel in press), Vic. (Shiel in prep.).

Brachionus keikoa Koste, 1979
Locality: S.A. (Koste 1979), Qld (Shiel in prep.).

Brachionus leydigii rotundus (Rousselet) 1907
1907 *Brachionus quadratus* var. *rotundus* Rousselet.
Locality: Vic. (Shiel in prep.).

Brachionus novaezealandia (Morris) 1912
Locality: S.A. (Shiel in press), Vic. (Shiel in prep.).

Brachionus patulus Müller, 1786
1948 *Platyias patulus* Gillard.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889).

Brachionus plicatilis Müller, 1786
1834 *Brachionus mülleri* Ehrenberg.
Locality: Qld (Russell 1961), Vic. (Walker 1973).

Brachionus quadridentatus melheni Barrois & Daday, 1894
1894 *Brachionus capsuliformis* var. *melheni* Barrois & Daday.
Locality: Vic. (Shiel 1979).

Brachionus quadridentatus quadridentatus Hermann, 1783
1766 *Brachionus capsuliflorus* Pallas.
1786 *Brachionus bakeri* Müller.
1889 *Brachionus bakeri* var. *longispinae* Thorpe.
Locality: Qld (Russell 1961), Vic. (Shiel 1978), W.A. (Berzins 1953).

Brachionus urceolaris bennini Leissling, 1924
Locality: S.A. (Shiel 1979), Vic. (Shiel in prep.).

Brachionus urceolaris nilsoni Ahlstrom, 1940
Locality: Vic. (Shiel in prep.).

Brachionus urceolaris rubens Ehrenberg, 1838
Locality: Qld (Colledge 1911, Russell 1961), Vic. (Anderson & Shephard 1892, Shiel 1979).

Brachionus urceolaris urceolaris (Müller) 1773
Locality: Qld (Colledge 1911), S.A. (Koste 1979), Vic. (Shiel 1979).

Cephalodella biungulata Wulfert, 1937
Locality: Vic. (Shiel in prep.)

Cephalodella catellina (Müller) 1786
1830 *Diglena catellina* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889).

Cephalodella forficata (Ehrenberg) 1832
1832 *Diaschiza forficata* Ehrenberg.
1832 *Notommata forficata*: Ehrenberg.
1886 *Diaschiza paeta* Gosse.
1886 *Furcularia ensifera* Gosse.
1903 *Diaschiza caeca* Dixon-Nuttall & Freeman.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, 1914).

Cephalodella forficula (Ehrenberg) 1832)
1838 *Furcularia forficula* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889; Murray 1913), Qld (Colledge 1914), W.A. (Berzins 1953).

Cephalodella gibba gibba (Ehrenberg) 1832
1886 *Diaschiza semiaperta* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), S.A. (Shiel in prep.), Vic. (Anderson & Shephard 1892).

Cephalodella gisleni Berzins, 1953
Locality: S.A. (Shiel in press), W.A. (Berzins 1953).

Cephalodella tenuiseta (Burn) 1890
Locality: W.A. (Berzins 1953).

Cephalodella tinca Wulfert 1937
Locality: Vic. (Shiel in prep.).

Ceratotrocha cornigera (Bryce) 1893
Locality: N.S.W. (Murray 1911).

Chromogaster ovalis (Bergendal) 1892
1892 *Anapus ovalus* Bergendal.
Locality: Qld (Colledge 1911).

Collotheca ambigua (Hudson) 1883
1883 *Floscularia ambigua* Hudson.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Collotheca campanulata (Dobie) 1849
1849 *Floscularia campanulata* Dobie
Locality: N.S.W. (Whitelegge. 1889), Qld (Colledge 1911, 1914), Vic. (Anderson & Shephard 1892).

Collotheca cornuta (Dobie) 1849
1849 *Floscularia cornuta* Dobie.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Collotheca coronetta (Cubbitt) 1869
1869 *Floscularia coronetta* Cubitt.
Locality: N.S.W. (Hudson 1889), Qld (Thorpe 1889), S.A. (Hudson 1889), Vic. (Anderson & Shephard 1892).

Collotheca cyclops Cubitt, 1871
Locality: N.S.W. (Whitelegge 1889).

Collotheca evansonii (Anderson & Shephard) 1892
1892 *Floscularia evansonii* Anderson & Shephard.
Locality: Vic. (Anderson & Shephard, 1892).

Collotheca longicaudata (Hudson) 1883.
1883 *Floscularia longicaudata* Hudson.
Locality: Qld (Colledge 1911, 1914).

Collotheca mutabilis (Hudson) 1885
1885 *Floscularia mutabilis* Hudson.
Locality: N.S.W. (Shiel in prep.).

Collotheca ornata (Ehrenberg) 1832
1832 *Floscularia ornata* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, Colledge 1911), Vic. (Anderson & Shephard 1892).

Collotheca pelagica (Rousselet) 1893
1893 *Floscularia pelagica* Rousselet
Locality: N.S.W. (Shiel, in prep.)

Collotheca trilobata (Collins) 1872
1872 *Floscularia trilobata* Collins.
Locality: Qld (Colledge 1914).

Colurella bicuspidata (Ehrenberg) 1832
1832 *Colurus bicuspidatus* Ehrenberg.
1832 *Colurus uncinata f. bicuspidata* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Colurella obtusa (Gosse) 1886
1886 *Colurus obtusa* Gosse.
1886 *Colurus amblytelus* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Russell 1961), W.A. (Berzins 1953).

Colurella uncinata deflexa (Ehrenberg) 1834
1834 *Colurus deflexus* Ehrenberg.
Locality: Qld (Colledge 1911).

Colurella uncinata uncinata (Müller) 1773
1773 *Brachionus uncinatus* Müller.
1830 *Colurus uncinatus*: Ehrenberg.
1886 *Colurus dactylotus* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Shiel in prep.).

Conochilus coenobasis (Skorikow) 1914
1914 *Conochiloides coenobasis* Skorikow.
Locality: Vic. (Berzins 1963).

Conochilus dossuarius (Hudson) 1885
1885 *Conochiloides dossuarius* Hudson.
Locality: N.S.W., S.A., Vic. (Shiel 1979, in press), Qld (Colledge 1911).

Conochilus hippocrepis (Schrank) 1830
1834 *Conochilus volvox* Ehrenberg.
Locality: Qld (Colledge 1909, Russell 1961), Vic. (Anderson & Shephard 1892).

Conochilus natans (Seligo) 1900
1900 *Tubicolaris natans* Seligo.
1904 *Conochiloides natans*: Hlava.

Locality: Qld (Russell 1961), S.A., Vic. (Shiel in press, in prep.).

Conochilus unicornis Rousselet, 1892
Locality: Qld (Colledge 1911), S.A., Vic. (Shiel in press, in prep.).

Cupelopagis vorax (Leidy) 1857
Locality: Vic. (Shiel 1979).

Cyrtonia tuba (Ehrenberg) 1834
1834 *Notommata tuba* Ehrenberg.
Locality: Qld (Colledge 1911).

Dicranophorus caudatus (Ehrenberg) 1834
1851 *Diglena biraphis* Gosse.
Locality: Qld (Thorpe 1889).

Dicranophorus forcipatus (Müller) 1786
1832 *Diglena forcipata*:Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914), Vic. Shiel in prep.).

Dicranophorus grandis (Ehrenberg) 1832
1832 *Diglena grandis* Ehrenberg.
Locality: Qld (Colledge 1911, 1914).

Dicranophorus haueriensis Wisniewski, 1939
Locality: Vic. (Shiel in prep.).

Dicranophorus lutkeni (Bergendal) 1892
Locality: Vic. (Shiel in prep.).

Diplois daviesiae Gosse, 1886
Locality: Qld (Thorpe 1887).

Dissotrocha aculeata (Ehrenberg 1832)
1832 *Philodina aculeata* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889).

Dissotrocha macrostyla (Ehrenberg, 1838)
Locality: N.S.W., Qld (Murray, 1911).

Elosa woralli Lord, 1891
Locality: N.S.W. (Murray 1913).

Encentrum felis (Müller) 1773
1886 *Proales felis*:Hudson & Gosse.
Locality: N.S.W. (Whitelegge 1889).

Encentrum putorius putorius Wulfert, 1936
Locality: Vic. (Shiel in prep.).

Encentrum saundersiae (Hudson) 1885
1885 *Taphrocampa saundersiae* Hudson.
Locality:

Enteroplea lacustris Ehrenberg, 1830
1889 *Triphylus lacustris*:Hudson & Gosse.
Locality: Qld (Colledge 1914).

Eosphora ehrenbergii Weber, 1918
1832 *Notommata najas* Ehrenberg.
Locality: Vic. (Anderson & Shephard, 1892).

Eosphora najas Ehrenberg, 1830
1838 *Eosphora digitata* Ehrenberg.
Locality: Qld (Colledge 1911).

Epiphanes brachionus (Ehrenberg) 1837
1837 *Notommata brachionus* Ehrenberg.
1886 *Notops brachionus* Hudson.
Locality: Qld (Colledge 1914), Vic. (Shephard 1899).

Epiphanes clavulata (Ehrenberg) 1832
1832 *Notommata clavulata* Ehrenberg.
1886 *Notops clavulatus*:Hudson.
Locality: Qld (Thorpe 1889, Colledge 1911, 1914), S.A., Vic. (Shiel 1979, in press).

Epiphanes senta (Müller) 1773
1830 *Hydatina senta* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Euchlanis deflexa (Gosse) 1851
Locality: Vic. (Shiel in prep.), W.A. (Berzins 1953).

Euchlanis dilatata dilatata Ehrenberg, 1832
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, Russell 1961), S.A. (Shiel, in press), Vic. (Anderson & Shephard 1892, Shephard 1899).

Euchlanis dilatata larga (Kutikova) 1959
Locality: Vic. (Shiel in prep.).

Euchlanis dilatata lucksiana Hauer, 1930
Locality: Vic., S.A. (Shiel in prep.).

Euchlanis incisa Carlin, 1939
Locality: Vic. (Shiel 1979).

Euchlanis lyra Hudson, 1886
Locality: Vic. (Berzins 1963).

Euchlanis meneta Myers, 1930
Locality: Vic. (Berzins 1963).

Euchlanis oropha Gosse, 1887
Locality: Qld (Colledge 1911).

Euchlanis parva Rousselet, 1892
Locality: Vic. (Shiel, in prep.).

Euchlanis triquetra Ehrenberg, 1838
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, 1889).

Filinia brachiata (Rousselet) 1901
1901 *Triarthra brachiata* Rousselet.
Locality: N.S.W. (Murray 1911).

Filinia longiseta (Ehrenberg) 1834
1834 *Triarthra longiseta* Ehrenberg.
Locality: N.S.W. (Shiel, 1978), Qld (Thorpe 1889, Colledge 1911), S.A (Shiel 1979), Vic. (Anderson & Shephard 1892).

Filinia longiseta limnetica (Zacharias) 1893
Locality: S.A. (Shiel in press).

Filinia opoliensis (Zacharias) 1898
1898 *Tetramastix opoliensis* Zacharias.
Locality: Qld (Russell 1961), S.A. (Shiel 1978).

Filinia passa (Müller) 1786
Locality: S.A., Vic. (Shiel in press).

Filinia pejleri Hutchinson, 1964
Locality: N.S.W., S.A. (Shiel in press).

Filinia pejleri grandis Koste, 1979
Locality: S.A. (Koste 1979).

Filinia terminalis (Plate) 1886
Locality: S.A. (Shiel, 1979, in press).

Floscularia conifera (Hudson) 1886
1886 *Melicerta conifera* Hudson.

Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1914), Vic. (Anderson & Shephard 1892).

Floscularia janus (Hudson) 1881
1886 *Melicerta janus* Hudson.
Locality: N.S.W. (Whitelegge 1889).

Floscularia melicerta (Ehrenberg) 1832
1886 *Melicerta tubicolaria* Gosse.
1899 *Melicerta fimbriata* Shephard & Stickland.
Locality: Qld (Colledge 1911, 1924), Vic. (Shephard & Stickland 1899).

Floscularia ringens (Linnaeus) 1958
1803 *Melicerta ringens*:Schrank.
Locality: N.S.W. (Whitelegge. 1889); Qld (Thorpe 1889, Colledge 1909), Vic. (Anderson & Shephard 1892).

Gastropus hyptopus (Ehrenberg) 1838
1838 *Notommata hyptopus* Ehrenberg.
Locality: Qld, (Russell 1961), N.S.W. (Shiel in prep.).

Gastropus minor (Rousselet) 1892
1892 *Notops minor* Rousselet.
Locality: Qld (Colledge 1911), N.S.W. (Shiel in prep.).

Gastropus stylifer Imhof, 1891
Locality: Qld (Colledge 1911).

Habrotrocha angusticollis (Murray) 1905
Locality: N.S.W., Qld (Murray 1911).

Habrotrocha appendiculata Murray, 1911
Locality: Qld (Laird 1956, Russell 1961)

Habrotrocha aspera (Bryce) 1892
Locality: N.S.W. (Murray 1911).

Habrotrocha constricta (Dujardin) 1841
Locality: N.S.W. (Murray 1911)

Habrotrocha caudata Murray, 1911
Locality: N.S.W., Qld (Murray 1911).

Habrotrocha leitgebii (Zelinka) 1886
Locality: N.S.W. (Murray 1911).

Habrotrocha longiceps (Murray) 1906
1906 *Callidina longiceps* Murray.
Locality:

Habrotrocha perforata (Murray 1906
Locality: N.S.W., Qld (Murray 1911).

Habrotrocha pusilla (Bryce) 1896
Locality: N.S.W. (Murray 1911).

Habrotrocha strangulata Murray, 1911
Locality: N.S.W. (Murray 1911).

Habrotrocha tridens (Milne) 1886
Locality: N.S.W. (Murray 1911).

Hexarthra fennica (Levander) 1892
Locality: Qld (Russell 1961).

Hexarthra intermedia (Wisziewski) 1929
Locality: N.S.W., S.A., Vic. (Shiel. 1978, in press).

Hexarthra jenkinae (Beauchamp) 1932
Locality: Vic. (Walker 1973).

Hexarthra mira (Hudson) 1871
1871 *Pedalia mira* Hudson
Locality: N.S.W., S.A., Vic. (Shiel in prep.), Qld (Russell 1961).

Horaella brehmi Donner, 1949
Locality: S.A. (Koste & Shiel. unpublished).

Itura aurita (Ehrenberg) 1830
1830 *Diglena aurita* Ehrenberg.
1836 *Eosphora aurita*:Werneck
Locality: Qld (Colledge 1911).

Keratella australis Berzins, 1963
1963 *Keratella quadrata australis* Berzins.
Locality: N.S.W., Qld, S.A., Vic. (Shiel. 1978, 1979), Vic. (Berzins 1963).

Keratella cochlearis cochlearis (Gosse) 1851
1851 *Anuraea cochlearis* Gosse.
Locality: Vic. (Berzins 1963), N.S.W., S.A. (Shiel 1978, 1979), Qld (Colledge 1911).

Keratella cochlearis hispida (Lauterborn) 1898
Locality: Qld (Russell 1961).

Keratella cruciformis (Thompson) 1892
Locality: Qld (Colledge 1914).

Keratella javana Hauer, 1937
1952 *Keratella carinata* Russell.
Locality: Vic. (Berzins 1963), W.A. Berzins 1953).

Keratella lenzi Hauer, 1953
Locality: Qld (Berzins 1955).

Keratella procurva (Thorpe) 1891
1891 *Anuraea procurva* Thorpe.
1943 *Keratella valga procurva*:Ahlstrom.
Locality: Vic (Berzins 1963), W.A. (Berzins 1953).

Keratella quadrata (Müller) 1786
1832 *Anuraea aculeata* Ehrenberg.
1838 *Anuraea curvicornis* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889), Vic. (Anderson & Shephard 1892).

Keratella serrulata (Ehrenberg) 1838
1838 *Anuraea serrulata* Ehrenberg.
Locality: Qld (Russell 1961), S.A. (Shiel in press).

Keratella shieli Koste, 1979
Locality: S.A. (Koste 1979).

Keratella slacki (Berzins) 1963
1963 *Keratella valga slacki* Berzins.
Locality: Vic. (Berzins 1963), S.A. (Shiel 1979).

Keratella tropica tropica (Apstein) 1907
Locality; Qld (Russell 1961), N.S.W. S.A., Vic. (Shiel 1979, in press).

Keratella valga (Ehrenberg) 1834
1834 *Anuraea valga* Ehrenberg.
Locality: Qld (Russell 1961), N.S.W., Vic. (Shiel 1978).

Lacinularia elliptica Shephard, 1897
Locality: Vic. (Shephard 1897), Qld (Colledge 1914), N.S.W., S.A. (Shiel in prep.).

Lacinularia elongata Shephard, 1897
Locality: Vic. (Shephard 1897).

Lacinularia flosculosa (Müller) 1758
1830 *Lacinularia socialis* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914), Vic. (Anderson & Shephard 1892).

Lacinularia ismaeloviensis (Poggenpol) 1872
1891 *Lacinularia natans* Western.
Locality: Vic. (Shiel in prep.).

Lacinularia pedunculata Hudson, 1889
Locality: N.S.W. (Hudson 1889), Vic. (Anderson & Shephard 1892).

Lacinularia racemovata Thorpe, 1892
Locality: Qld (Colledge 1914).

Lacinularia reticulata Anderson & Shephard, 1892
Locality: Vic. (Anderson & Shephard 1892).

Lacinularia striolata Shephard, 1899
Locality: Vic. (Shephard 1899).

Lecane arcuata (Bryce) 1891
1891 *Monostyla arcuata* Bryce.
Locality: Qld (Russell 1961).

Lecane batillifer (Murray) 1913
1913 *Monostyla batillifer* Murray
Locality: N.S.W. (Murray 1913).

Lecane brachydactyla (Stenroos) 1898
1898 *Cathypna brachydactyla* Stenroos.
Locality: Qld (Colledge 1914).

Lecane bulla bulla (Gosse) 1851
1851 *Monostyla bulla* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, Laird 1956), W.A. (Berzins 1953), Vic. (Berzins 1963).

Lecane closterocerca (Schmarda) 1895
1926 *Monostyla closterocerca*: Harring and Myers.
Locality: W.A. (Berzins 1953), Vic. (Shiel in prep.).

Lecane cornuta (Müller) 1786
1786 *Trichoda cornuta*: Müller.
1830 *Monostyla cornuta* Ehrenberg.
1830 *Monostyla robusta* Ehrenberg.
Locality: N.S.W. (Sudzuki & Timms, 1977); Qld. (Colledge 1911).

Lecane crenata (Harring) 1913
1913 *Monostyla crenata* Harring.
Locality: Qld (Russell 1961), Vic. (Shiel in prep.).

Lecane flexilis (Gosse) 1886
Locality: Vic. (Shiel, in prep.).

Lecane hamata (Stokes) 1896
1896 *Monostyla hamata* Stokes.
Locality: Qld (Russell 1961), WA (Berzins 1963), Vic. (Shiel in prep.), N.S.W. (Murray 1913).

Lecane ichthyoura (Anderson & Shephard) 1892
1892 *Distyla ichthyoura* Anderson & Shephard.
Locality: Vic. (Anderson & Shephard 1892).

Lecane leontina (Turner) 1892
1892 *Cathypna leontina* Turner.
Locality: Qld (Colledge 1911).

Lecane luna luna (Müller) 1776
1886 *Cathypna luna*: Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Russell 1961), S.A. (Shiel in press), W.A. (Berzins 1953).

Lecane lunaris (Ehrenberg) 1832
1832 *Monostyla lunaris* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889), S.A., Vic. (Shiel in press).

Lecane nana (Murray) 1913
1913 *Cathypna nana* Murray.
Locality: Qld (Russell 1961).

Lecane ohioensis (Herrick) 1885
Locality: Qld (Colledge 1914). Vic. (Shiel in prep.).

Lecane papuana (Murray) 1913
Locality: Qld (Russell 1961).

Lecane quadridentata (Ehrenberg) 1832
1832 *Monostyla quadridentata* Ehrenberg
Locality: Qld (Colledge 1911). Vic. (Anderson & Shephard 1892).

Lecane signifera ploenensis (Voigt) 1902
Locality: Qld (Russell 1961), N.S.W. (Shiel, in prep.).

Lecane signifera signifera (Jennings) 1896
Locality: Qld (Shiel in prep.).

Lecane spenceri (Shephard) 1892
1892 *Cathypna spenceri* Shephard.
Locality: Vic. (Shephard 1892).

Lecane stenroosi (Meissner) 1908
1908 *Monostyla stenroosi* Meissner.
Locality: Qld (Laird 1956, Russell 1957), N.S.W. (Sudzuki & Timms 1977).

Lecane styrax (Harring & Myers) 1926
Locality: Qld (Russell 1961).

Lecane ungulata ungulata (Gosse) 1887
1887 *Cathypna ungulata* Gosse.
Locality: Qld (Colledge 1941, Russell 1961).

Lecane ungulata australiensis Koste 1979
Locality: Vic. (Koste 1979).

Lepadella acuminata (Ehrenberg) 1834
1834 *Metopidia acuminata* Ehrenberg.
Locality: Qld (Colledge 1911).

Lepadella ehrenbergi (Perty) 1850
1850 *Metopidia ehrenbergi* Perty.
Locality: N.S.W. (Murray 1913).

Lepadella heterostyla (Murray) 1913
1913 *Metopidia heterostyla* Murray.
Locality: N.S.W. (Murray 1913)

Lepadella oblonga (Ehrenberg) 1834
1834 *Metopidia oblonga* Ehrenberg.
Locality: Qld (Colledge 1914).

Lepadella ovalis (Müller) 1786
1832 *Metopidia lepadella* Ehrenberg.
1851 *Metopidia solidus* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1911), Vic. (Anderson & Shephard 1892).

Lepadella patella patella (Müller) 1773
1889 *Metopidia lepadella* Hudson & Gosse.
1896 *Metopidia collaris* Stokes.
Locality: N.S.W. (Whitelegge 1889, Murray 1913), Qld (Colledge 1911), Vic. (Shiel in prep.), W.A. (Berzins 1953).

Lepadella quinquecostata (Lucks) 1912
1912 *Metopidia quinquecostata* Lucks.
Locality: N.S.W. (Murray 1913).

Lepadella rhomboides (Gosse 1886)
1886 *Metopidia rhomboides* Gosse.
Locality: N.S.W. (Murray 1911).

Lepadella salpina (Ehrenberg) 1834
1886 *Metopidia oxysternum* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Lepadella triptera (Ehrenberg) 1830
1830 *Metopidia triptera* Ehrenberg.
Locality: Qld (Colledge 1911).

Lepadella vitrea (Shephard) 1911
1892 *Metopidia ovalis* (*non* Müller) Anderson & Shephard.
1911 *Metopidia vitrea* Shephard.
Locality: Qld (Colledge 1914), Vic. (Anderson & Shephard 1892).

Limnias ceratophylli Schrank 1803
1862 *Melicerta ceratophylli* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1909), Vic. (Anderson & Shephard 1892).

Limnias granulosus Weber 1888
Locality: Vic. (Anderson & Shephard, 1892).

Limnias melicerta Wiesse, 1848
1854 *Limnias annulatus* Bailey.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887), Vic. (Anderson & Shephard 1892).

Lophocharis salpina (Ehrenberg) 1834
1851 *Metopidia oxysternum* Gosse.
Locality: Qld (Colledge 1914), Vic. (Shiel in prep.).

Macrochaetus collinsi (Gosse) 1867
1867 *Dinocharis collinsi* Gosse.
Locality: Qld (Colledge 1911).

Macrochaetus subquadratus (Perty) 1850
1850 *Polychaetus subquadratus* Perty.
Locality: N.S.W. (Murray 1913).

Macrotrachela armillata (Murray) 1911
1911 *Callidina armillata* Murray.
Locality: N.S.W. (Murray 1911).

Macrotrachela ehrenbergi (Janson) 1893
1893 *Callidina ehrenbergi* Janson.
Locality: N.S.W. (Murray 1911).

Macrotrachela formosa (Murray) 1906
1906 *Callidina formosa* Murray.
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela habita (Bryce) 1894
1894 *Callidina habita* Bryce.
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela lepida (Murray) 1911
1911 *Callidina lepida* Murray.
Locality: N.S.W. (Murray 1911).

Macrotrachela longistyla (Murray) 1911
1911 *Callidina longistyla* Murray.
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela microcornis (Murray) 1911
1911 *Callidina microcornis* Murray.
Locality: N.S.W. (Murray 1911).

Macrotrachela mirabilis (Murray) 1911
1911 *Callidina mirabilis* Murray.
Locality: N.S.W. (Murray 1911).

Macrotrachela multispinosa Thompson, 1892
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela papillosa Thompson, 1892
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela plicata (Bryce) 1896
1896 *Callidina plicata* Bryce.
Locality: N.S.W. (Murray 1911).

Macrotrachela punctata (Murray) 1911
1911 *Callidina punctata* Murray.
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela quadricornifera (Milne) 1886
1886 *Callidina quadricornifera* Milne.
Locality: N.S.W., Qld (Murray 1911).

Macrotrachela serrulata (Murray) 1911
1911 *Callidina serrulata* Murray.
Locality: N.S.W. (Murray 1911).

Microcodidus chlaena (Gosse) 1886
1886 *Stephanops chlaena* Gosse.
Locality: Qld (Colledge 1914).

Microdon clavus Ehrenberg 1830
Locality: N.S.W. (Whitelegge 1889).

Mniobia russeola (Zelinka) 1891
Locality: N.S.W. (Murray 1911).

Mniobia scabrosa Murray, 1911
Locality: N.S.W. (Murray 1911).

Mniobia tetraodon (Ehrenberg) 1848
Locality: N.S.W. (Murray 1911).

Monommata aequalis (Ehrenberg) 1832
1886 *Furcularia aequalis*:Hudson & Gosse.
Locality: Qld (Colledge 1911).

Monommata longiseta (Müller) 1786
1776 *Cercaria longiseta* Müller.
1786 *Vorticella longiseta*:Müller.
1816 *Furcularia longiseta*:Lamarck.

Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1911, Laird 1956, Russell 1957).

Mytilina mucronata (Müller) 1773
Locality: Vic. (Shiel in prep.).

Mytilina trigona (Gosse) 1851
1851 *Diplax trigona* Gosse.
Locality: Qld (Colledge 1911).

Mytilina ventralis (Ehrenberg) 1832
1832 *Salpina ventralis* Ehrenberg.
1886 *Salpina eustala* Gosse.
1886 *Salpina macrocantha* Gosse.
1891 *Salpina cortina* Thorpe.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, 1889, Colledge 1911, 1914, Russell 1961), Vic. (Shiel in prep.).

Mytilina ventralis brevispina (Ehrenberg) 1832
1832 *Salpina brevispina* Ehrenberg.
Locality: Qld (Colledge 1911), Vic. (Anderson & Shephard 1892).

Notommata aurita (Müller) 1786
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Anderson & Shephard 1892).

Notommata cerberus (Gosse) 1886
1886 *Copeus cerberus* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1899).

Notommata collaris Ehrenberg, 1832
Locality: N.S.W. (Whitelegge 1889).

Notommata copeus Ehrenberg, 1834
1834 *Notommata centrura* Ehrenberg.
1886 *Copeus ehrenbergi* Hudson & Gosse.
1886 *Copeus labiatus* Gosse.
1897 *Copeus copeus*:Collin.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892), Qld (Colledge 1911).

Notommata cyrtopus Gosse, 1886
Locality: N.S.W. (Whitelegge 1889).

Notommata lacinulata Ehrenberg, 1830
Locality: Qld (Colledge 1914).

Notommata pachyura (Gosse) 1886.
1832 *Notommata ansata* Ehrenberg.
1886 *Copeus pachyurus* Gosse.
Locality: Vic. (Anderson & Shephard 1892); N.S.W. (Whitelegge 1889), Qld (Thorpe 1889, Colledge 1911).

Notommata silpha (Gosse, 1887)
1886 *Notommata forcipata* Gosse.
Locality: N.S.W. (Whitelegge 1889).

Notommata tripus Ehrenberg, 1838
1886 *Notommata pilarius* Gosse.
Locality: N.S.W. (Whitelegge 1889).

Otostephanus auriculatus (Murray) 1911
1911 *Habrotrocha auriculata* Murray.
Locality: N.S.W. (Murray 1911).

Philodina australis Murray 1911
Locality: N.S.W. (Murray 1911).

Philodina brevipes Murray, 1902
Locality: N.S.W. (Murray 1911).

Philodina citrina Ehrenberg, 1832
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889), Vic. (Anderson & Shephard 1892).

Philodina megalotrocha Ehrenberg, 1832
Locality: Qld (Colledge 1914), Vic. (Shiel in prep.).

Philodina plena (Bryce) 1894
Locality: N.S.W., Qld (Murray 1911).

Philodina roseola Ehrenberg, 1832
Locality: N.S.W. (Whitelegge 1889), Vic (Anderson & Shephard 1892).

Philodina rugosa Bryce, 1903
Locality: N.S.W., Qld (Murray 1911).

Philodina vorax (Janson) 1893
Locality: Qld (Murray 1911).

Platyias quadricornis (Ehrenberg) 1832
1832 *Noteus quadricornis* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914), Vic. (Anderson & Shephard 1892, Berzins 1963).

Ploesoma lenticulare (Herrick) 1855
1838 ?*Euchlanis lynceus* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889).

Pleuretra alpium (Ehrenberg) 1853
1853 *Callidina alpium* Ehrenberg.
Locality: N.S.W., Qld (Murray 1911).

Pleuretra humerosa (Murray) 1905
1905 *Philodina humerosa* Murray.
Locality: N.S.W. (Murray 1911).

Pleurotrocha petromyzon Ehrenberg, 1830
1886 *Proales petromyzon*:Hudson & Gosse.
Locality: N.S.W. (Whitelegge 1889), Vic. (Shiel in prep.).

Polyarthra dolichoptera (Idelson) 1925
Locality: N.S.W. (Shiel in prep).

Polyarthra longiremis Carlin, 1943
Locality: Qld (Russell 1961), Vic. (Shiel in prep.).

Polyarthra remata (Skorikow) 1896
Locality: Vic. (Berzins 1963).

Polyarthra vulgaris Carlin, 1943
1838 *Polyarthra platyptera* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, 1889, Russell 1961), Vic. (Anderson & Shephard 1892, Shiel 1978), S.A. (Shiel in press.).

Pompholyx complanata Gosse, 1851
Locality: Qld (Russell 1961), N.S.W. S.A., Vic. (Shiel in press).

Pompholyx sulcata (Hudson) 1885
Locality: N.S.W. (Sudzuki & Timms in prep.), Vic. (Shiel in prep.).

Proales daphnicola Thompson, 1842
Locality: Vic. (Shiel in prep.).

Proales decipiens (Ehrenberg) 1831
1831 *Notommata decipiens* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889).

Proales gigantea (Glascott) 1893
1893 *Notommata gigantea* Glascott.
Locality: Qld (Laird 1956, Russell 1957).

Proales micropus (Gosse) 1886
1886 *Furcularia micropus* Gosse.
Locality: Qld (Colledge 1911).

Proales parasita (Ehrenberg) 1838
1838 *Notommata parasita* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914).

Proales similis exoculis Berzins, 1953
Locality: W.A. (Berzins 1953).

Proales sordida Gosse, 1881
Locality: Qld (Colledge 1911).

Proales werneckii (Ehrenberg) 1834
1834 *Notommata werneckii* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889).

Proalinopsis caudatus (Collins) 1872
1886 *Copeus caudatus* Hudson & Gosse.
1872 *Notommata caudata*:Collins.
Locality: N.S.W. (Whitelegge 1889)

Ptygura brachiata (Hudson) 1886
1886 *Oecistes brachiatus* Hudson.
Locality: Qld (Colledge 1911).

Ptygura cristata (Murray) 1913
1913 *Oecistes cristatus* Murray.
Locality: N.S.W. (Murray 1913).

Ptygura crystallina (Ehrenberg) 1834
1834 *Oecistes crystallinus* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Anderson & Shephard 1892).

Ptygura intermedia (Davis) 1867
1867 *Oecistes intermedius* Davis.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Ptygura longicornis (Davis) 1867
1867 *Oecistes longicornis* Davis.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Ptygura melicerta (Ehrenberg) 1832
1886 *Oecistes ptygura* Hudson & Gosse
Locality: N.S.W. (Whitelegge 1889).

Ptygura pilula (Cubitt) 1872
1872 *Melicerta pilula* Cubitt.
1878 *Oecistes pilula*:Wills.
Locality: N.S.W. (Whitelegge 1889).

Ptygura wilsonii (Anderson & Shephard) 1892
1892 *Oecistes wilsonii* Anderson & Shephard.
Locality: Vic. (Anderson & Shephard 1892).

Resticula melandocus (Gosse) 1887
1887 *Furcularia melandocus* Gosse.
Locality: Qld (Colledge 1911).

Rhinoglena frontalis (Ehrenberg) 1853
Locality: Vic. (Shiel in prep.).

Rotaria exoculis (de Koning) 1947.
Locality: W.A. (Berzins 1953).

Rotaria haptica (Gosse) 1886
1886 *Rotifer hapticus* Hudson & Gosse.
Locality: N.S.W. (Murray 1911).

Rotaria macroceros (Gosse) 1851
1851 *Rotifer macroceros* Gosse.
Locality: N.S.W. (Whitelegge 1889).

Rotaria macrura (Ehrenberg) 1832
1832 *Rotifer macrurus* Ehrenberg.
Locality: Qld (Thorpe 1889), N.S.W (Shiel in prep.).

Rotaria montana (Murray) 1911
1911 *Rotifer montanus* Murray.
Locality: N.S.W. (Murray 1911).

Rotaria neptunia (Ehrenberg) 1832
1832 *Actinurus neptunius* Ehrenberg.
1900 *Rotifer neptunius*:Jennings.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, 1889), W.A. (Berzins 1953), Vic. (Shiel in prep.).

Rotaria rotatoria (Pallas) 1766
1801 *Rotifer vulgaris* Schrank.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889), Vic. (Anderson & Shephard 1892).

Rotaria sordida (Western) 1893
1910 *Rotifer longirostris* Bryce.
Locality: N.S.W., Qld (Murray 1911).

Rotaria tardigrada (Ehrenberg) 1832
1838 *Rotifer tardus* Ehrenberg.
Locality: Qld (Thorpe 1889), Vic. (Anderson & Shephard 1892).

Rousseletia parrotti (Russell) 1947
Locality: N.S.W. (Sudzuki & Timms 1977).

Scaridium longicaudum (Müller) 1786
1786 *Trichoda longicauda* Müller.
1886 *Scaridium eudactylotum* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, 1889), Vic. (Shiel in prep.).

Scepanotrocha rubra Bryce, 1910
Locality: N.S.W. (Murray 1911).

Sinantherina semibullata (Thorpe) 1889
1889 *Megalotrocha semibullata* Thorpe.
-Locality: Qld (Thorpe 1889, Colledge 1914).

Sinantherina socialis (Linnaeus) 1758
1838 *Megalotrocha alboflavicans* Ehrenberg.
Locality: Qld (Colledge 1914, Russell 1961).

Sinantherina spinosa (Thorpe) 1893
1893 *Megalotrocha spinosa* Thorpe.
Locality: Qld (Colledge 1914).

Squatinella longispinata (Tatem) 1867
1867 *Stephanops longispinatus* Tatem.
1886 *Stephanops unisetatus* Hudson & Gosse.
Locality: N.S.W. (Whitelegge 1899).

Squatinella rostrum (Schmarda) 1846
1830 *Stephanops lamellaris* Ehrenberg
Locality: Qld (Thorpe 1889).

Squatinella tridentata (Fresenius) 1858
1889 *Stephanops intermedius* Burn.
Locality: Qld (Colledge 1914).

Squatinella tridentata mutica (Ehrenberg) 1832
1832 *Stephanops muticus* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Vic. (Anderson & Shephard 1892).

Stephanoceros fimbriatus (Goldfuss, 1820)
1832 *Stephanoceros eichhornii* Ehrenberg.
1832 *Stephanops eichhornii*:Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, 1914).

Stephanoceros millsi (Kellicott) 1885
1885 *Floscularia millsi* Kellicott.
Locality: N.S.W. (Whitelegge 1889).

Synchaeta baltica Ehrenberg 1834
Locality: N.S.W. (Whitelegge 1889).

Synchaeta longipes (Gosse) 1887
Locality: Vic. (Shiel in prep.).

Synchaeta oblonga Ehrenberg, 1832
Locality: N.S.W. (Shiel in prep.).

Synchaeta pectinata Ehrenberg, 1832
Locality: Qld (Russell 1961), Vic. (Shephard 1911).

Synchaeta stylata Wierzejski, 1893
Locality: Qld (Colledge 1911), S.A. (Shiel in prep.).

Synchaeta tremula (Müller) 1786
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Anderson & Shephard 1892).

Taphrocampa annulosa Gosse, 1851
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Taphrocampa selenura Gosse, 1887
Locality: N.S.W. (Whitelegge 1889).

Testudinella incisa (Ternetz) 1892
1892 *Pterodina incisa* Ternetz.
Locality: Qld (Colledge 1914).

Testudinella insinuata Hauer, 1938
Locality: Qld (Russell, 1961).

Testudinella intermedia (Anderson) 1889
1889 *Pterodina intermedia* Anderson.
Locality: Vic. (Anderson & Shephard 1892).

Testudinella patina (Hermann) 1783
1830 *Pterodina patina*:Ehrenberg.
1871 *Pterodina valvata* Hudson.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1887, Russell 1961), Vic. (Shephard 1899).

Testudinella reflexa (Gosse) 1887
1887 *Pterodina reflexa* Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914).

Testudinella trilobata (Anderson & Shephard) 1892
1892 *Pterodina trilobata* Anderson & Shephard.
Locality: Vic. (Anderson & Shephard 1892).

Tetrasiphon hydrocora Ehrenberg, 1840
1885 *Copeus spicatus* Hudson.
Locality: N.S.W. (Whitelegge 1889).

Trichocerca bicristata (Gosse) 1887
1887 *Mastigocerca bicristata* Gosse.
1903 *Rattulus bicristatus*:Jennings.
Locality: Qld (Colledge 1911, 1914).

Trichocerca birostris (Minkiwicz) 1900
1900 *Mastigocerca birostris* Minkiwicz
Locality: Qld (Colledge 1914).

Trichocerca brachyura (Gosse) 1851
1851 *Monocerca brachyura* Gosse.
1886 *Coelopus brachyurus*:Hudson & Gosse.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Trichocerca capucina (Wierzejski & Zacharias) 1893
1903 *Rattulus capucinus* Jennings.
Locality: N.S.W. (Murray 1913), Qld (Russell 1961).

Trichocerca cylindrica chattoni (De Beauchamp) 1907
Locality: N.S.W. (Koste unpubl.).

Trichocerca dixonnuttalli (Jennings) 1903
1903 *Diurella dixon-nuttalli* Jennings
Locality: Qld (Russell 1961).

Trichocerca elongata (Gosse) 1886
1886 *Mastigocerca elongata* Gosse.
1903 *Rattulus elongata* Jennings.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, 1914).

Trichocerca insignis (Herrick) 1885
Locality: N.S.W. (Shiel in prep.).

Trichocerca longiseta (Schrank) 1802
1886 *Mastigocerca bicornis* Hudson & Gosse.
1903 *Rattulus longiseta* Jennings.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Trichocerca mucosa (Stokes) 1896
1896 *Mastigocerca mucosa* Stokes.
1903 *Rattulus mucosus* Jennings.
Locality: Qld (Colledge 1911).

Trichocerca porcellus (Gosse) 1886
1851 *Coelopus porcellus* Gosse.
1903 *Diurella porcellus* Jennings
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Trichocerca porcellus (Gosse) 1886
1851 *Coelopus porcellus* Gosse.

1903 *Diurella porcellus* Jennings.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Trichocerca pusilla (Jennings) 1903
1903 *Rattulus pusillus* Jennings.
Locality: W.A. (Berzins 1953).

Trichocerca rattus (Müller) 1776
1830 *Mastigocerca carinata* Ehrenberg.
1860 *Rattulus carinatus* Lamarck.
1903 *Rattulus rattus* Jennings.
1913 *Trichocerca cristata* Harring.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911, Russell 1961), Vic. (Anderson and Shephard 1892).

Trichocerca rattus carinata (Ehrenberg) 1830
Locality: Vic. (Shiel in prep.).

Trichocerca rousseleti (Voigt) 1902
Locality: S.A. (Shiel in prep.).

Trichocerca similis (Wierzejski) 1893
1851 *Mastigocerca stylata* Gosse.
1878 *Diurella stylata* Eyferth.
1893 *Rattulus bicornis* Western.
1900 *Mastigocerca birostris* Minkiewicz.
Locality: Qld (Thorpe 1889; Colledge 1911, 1914; Russell 1961), Vic., N.S.W. (Shiel in prep.)

Trichocerca stylata (Gosse) 1851
1903 *Rattulus stylatus* Jennings.
Locality: Vic. (Shiel in prep.).

Trichocerca tenuior (Gosse) 1886
1886 *Coelopus tenuior* Gosse.
1903 *Diurella tenuior* Jennings.
Locality: N.S.W. (Whitelegge 1889), Qld (Thorpe 1889).

Trichocerca tigris (Müller) 1786
1786 *Rattulus tigris* Müller.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911), Vic. (Shiel in prep.).

Trichocerca weberi (Jennings) 1903
1903 *Diurella weberi* Jennings.
Locality: Qld (Russell 1961).

Trichotria pocillum (Müller) 1776
1830 *Dinocharis pocillum* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1911).

Trichotria tetractis (Ehrenberg) 1830
1830 *Dinocharis tetractis* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914), Vic. (Anderson & Shephard 1892)

Trichotria truncata (Whitelegge) 1889
1889 *Dinocharis truncatum* Whitelegge.
Locality: N.S.W. (Whitelegge 1889).

Tripleuchlanis plicata (Levander) 1894
1894 *Euchlanis plicata* Levander
Locality: Qld (Russell 1961).

Trochosphaera equatorialis (Semper) 1872
Locality: Qld (Thorpe 1889)

The following species are listed by Pejler (1977:266, 267; Table 1) as recorded from the Australian region. They are listed separately from the Index, as no published Australian record could be found, although most are recorded from New Zealand by Russell (1960).

Brachionus zahniseri Ahlstrom, 1934.
Keratella ahlstromi Russell, 1951.
Keratella crassa Ahlstrom, 1943.
Keratella edmondsoni Ahlstrom, 1943.
Keratella sancta Russell, 1944.
Notholca foliacea (= *Argonotholca foliacea* Ehrenberg, 1838).
Notholca squamula (Müller) 1786.

Incertae sedis

In the course of the literature search several names were found to be *nomina dubia*. These, together with valid species for which inadequate information was available for inclusion in the Index, are listed below. Source and locality data are also given

Cochleare turbo Gosse, 1886
Locality: Qld (Colledge 1911)

Floscularia chimaera Hudson & Gosse, 1889.
Locality: Qld (Hudson & Gosse 1889).

Melicerta bursdorfiae Colledge, 1924
Locality: Qld (Colledge 1924).

Melicerta coloniensis
Locality: Qld (Colledge 1924).

Microdida chlaena (= ?*Microcodides chlaena* Gosse)
Locality: Qld (Colledge 1914).

Rattulus sejunctipes Gosse 1886
1903 *Diurella sejunctipes* Jennings.
Locality: N.S.W. (Whitelegge 1889).

Synchaeta ovalis (= ?*Chromogaster ovalis* Bergendal)
Locality: Qld (Colledge 1911)

Triopthalmus dorsualis (Ehrenberg) 1830
1830 *Notops dorsualis* Ehrenberg.
Locality: N.S.W. (Whitelegge 1889), Qld (Colledge 1914).

Triopthalmus longiseta
Locality: Qld (Colledge 1911).

Acknowledgments

Dr T. J. Hillman and the staff of the Albury-Wodonga Development Corporation Laboratories at Bandiana, Victoria, made available plankton collections, expertise and laboratory facilities, and assisted in field work. Their help is gratefully acknowledged, as is the financial support of the A.W.D.C. Dr B. V. Timms, University of Canterbury, Christchurch, N.Z., is thanked for access to an unpublished MS. Dr K. F. Walker is thanked for his comments on a draft MS.

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HOLOCENE STRATIGRAPHY AND EVOLUTION OF THE COOKE PLAINS EMBAYMENT, A FORMER EXTENSION OF LAKE ALEXANDRINA, SOUTH AUSTRALIA

BY C. C. VON DER BORCH AND M. ALTMANN

Summary

The Cook Plains Embayment occupies an emergent area that was recently innundated by Lake Alexandrina. The embayment is underlain by a Holocene sedimentary succession several metres thick, the stratigraphy of which reflects some aspects of the late Holocene climatic and other changes in the vicinity of the River Murray delta system. The most likely cause of the late Holocene expansion of the lake system is considered to have been increased inflow to the lake from the River Murray, during the world-wide "pluvial" period that occurred 5000-8000 years ago. A contributing cause may also have been the peak of the Holocene marine transgression which is dated in southern Australia at around 6000 years ago. The slightly higher than present sealevel stand may have backed up lake waters by raising baselevel, with a consequent rise in groundwater table. Some direct inflow of ocean water may have also taken place at this time. Subsequent to the high lake stand, increased aridity combined with a slight sealevel fall lowered lake level approximately to its present situation. The paleaoclimatic events deduced from the stratigraphy of the Cooke Plains Embayment are consistent with those proposed by other workers from stratigraphic evidence in lakes of western Victoria.

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VON DER BORCH, C. C. and ALTMANN, M. (1979). Holocene stratigraphy and evolution of the Cooke Plains Embayment, a former extension of Lake Alexandrina, South Australia. *Trans. R. Soc. S. Aust.* **103**(3), 69-78, 31 May, 1979.

The Cooke Plains Embayment occupies an emergent area that was recently inundated by Lake Alexandrina. The embayment is underlain by a Holocene sedimentary succession several metres thick, the stratigraphy of which reflects some aspects of the late Holocene climatic and other changes in the vicinity of the River Murray delta system. The most likely cause of the late Holocene expansion of the lake system is considered to have been increased inflow to the lake from the River Murray, during the world-wide "pluvial" period that occurred 5000-8000 years ago. A contributing cause may also have been the peak of the Holocene marine transgression which is dated in southern Australia at around 6000 years ago. The slightly higher than present sealevel stand may have backed up lake waters by raising baselevel, with a consequent rise in groundwater table. Some direct inflow of ocean water may have also taken place at this time. Subsequent to the high lake stand, increased aridity combined with a slight sealevel fall lowered lake level approximately to its present situation. The paleoclimatic events deduced from the stratigraphy of the Cooke Plains Embayment are consistent with those proposed by other workers from stratigraphic evidence in lakes of western Victoria

Introduction

The River Murray forms a major part of Australia's largest drainage system. Its sediment load at present is being deposited in a marine-dominated delta comprising lakes Alexandrina and Albert, the north lagoon of the Coorong, and the adjacent continental shelf. In the recent past, fluvial as well as lacustrine and estuarine sediments were deposited over a much more extensive area during a period when water level was somewhat higher than at present. The region involved is illustrated in part in Figure 1 and includes the present lakes and lagoon, as well as marginal and now essentially subaerial areas shown by the diagonally striped symbol

The youngest sediments from beneath the lakes and exposed former extensions of the lakes preserve a record of the Holocene history of the River Murray delta. The contrasting stratigraphic units reflect notable climate and sealevel changes that have typified the past few thousand years.

The object of this paper is to present preliminary interpretations of the Holocene sedimentary units of one of the exposed, relatively accessible portions of the delta complex, the Cooke Plains Embayment (Figs 1-2).

Previous work

Soil surveys by Taylor & Poole (1931), Wells (1955) and de Mooy (1959a, 1959b) provide some initial data in the study area. De Mooy (1959a) specifically documented some of the sediments on the stranded lake flats, informally designating the characteristically dark-coloured upper sediments in areas such as the Cooke Plains Embayment as the Malcolm Combination. Sprigg (1959) described the widespread siliceous and calcareous eolian sand accumulations which form the morphological framework of the region surrounding the lakes.

Physiography

The Cooke Plains Embayment (Figs 1-2) constitutes one of the areas formerly occupied by Lake Alexandrina. The Embayment is a low-lying, east-west trending corridor between

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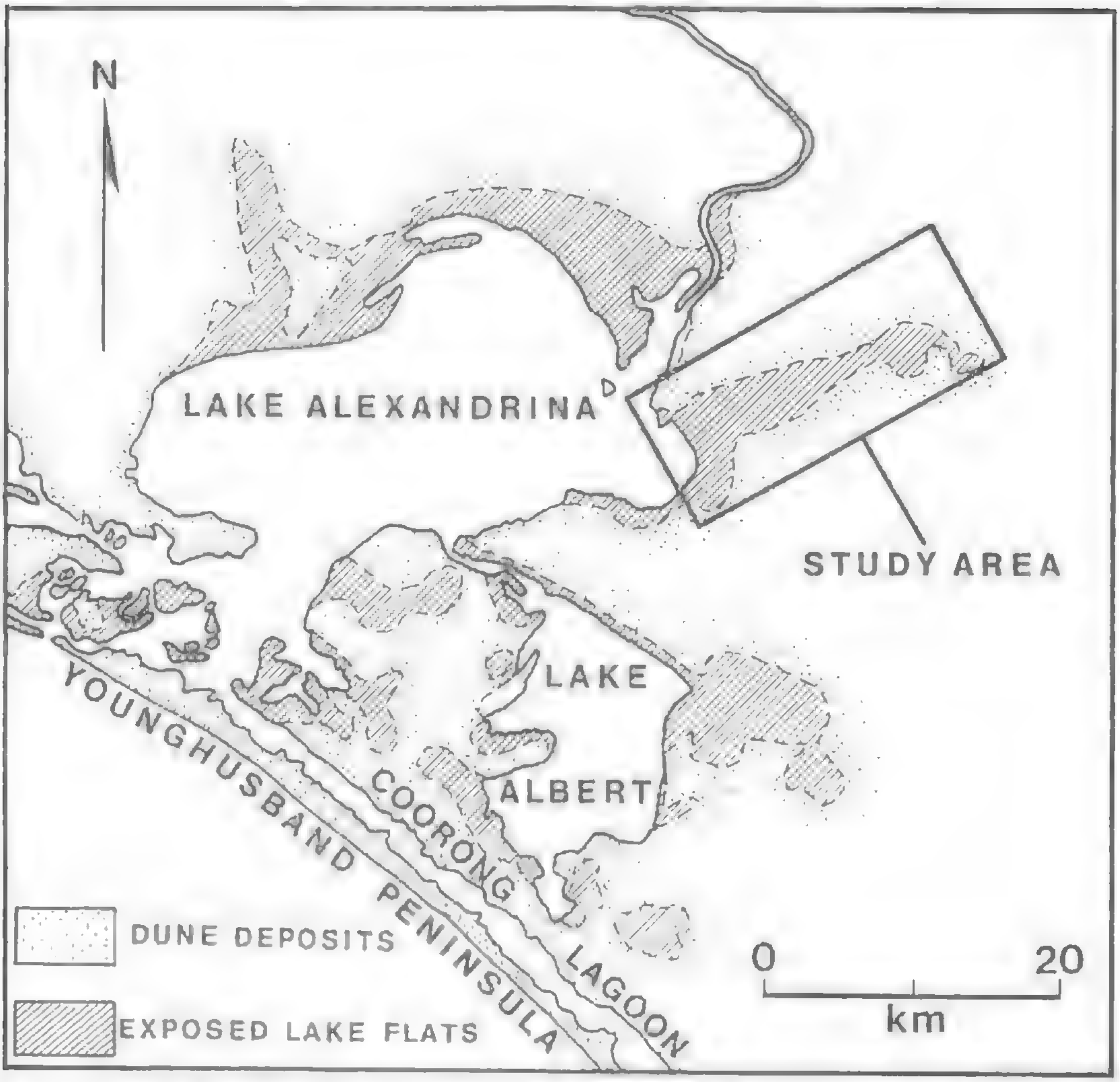

Fig. 1. Locality of study area (Cooke Plains Embayment), showing its relationship to Lake Alexandrina. The exposed lake flats approximately represent the region covered by ancestral Lake Alexandrina during its maximum stand several thousand years ago.

somewhat more elevated dunes. Two cheniers of siliceous sand (Fig. 2) occur at the western end of the embayment adjacent to present-day Lake Alexandrina and these have been described by de Mooy (1959a). Two gypsum lunettes (Campbell 1968), occur adjacent to the inland (eastern) end of the embayment, one of which lies within the boundary of Fig. 2

Sand dunes, mainly of Pleistocene emplacement, border the embayment. These comprise unconsolidated siliceous sands at the surface, generally overlying a Pleistocene calcrete developed on calcareous dunes. The calcrete is onlapped by Holocene sediments of the embayment. Some of these dunes may represent Pleinstocene marine strandline deposits formed during interglacial high sealevel stands (Sprigg 1952, 1959). Others are related to sand-drifts of the arid phase which coincided with the last glacial maximum.

The surface of the Cooke Plains Embayment is notably flat. It is largely vegetated by halophytes such as *Salicornia australis* and, as such, contrasts with the surrounding undulating topography of the dune systems. The embayment surface is covered in marginal areas by a widespread black soil.

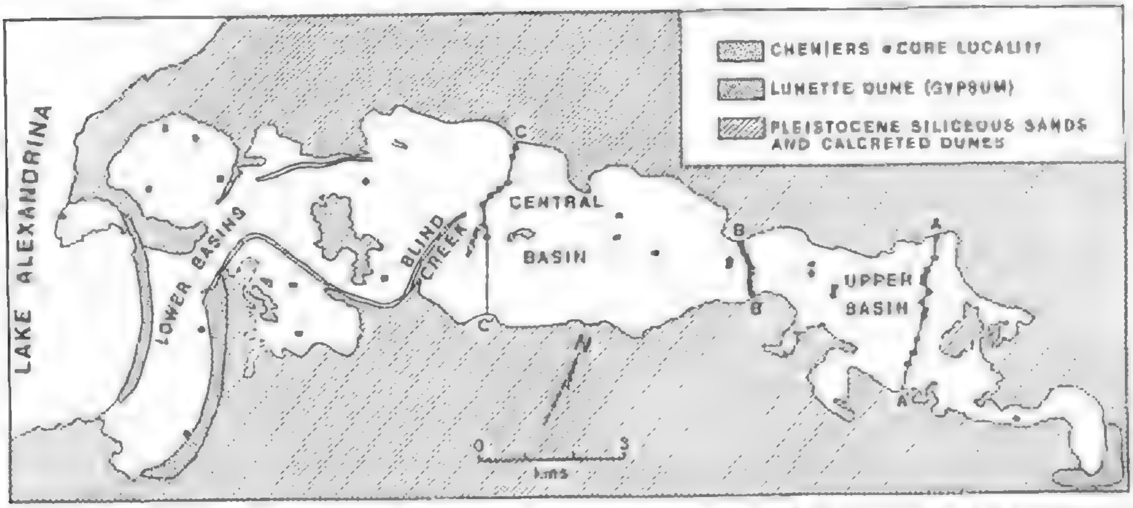

Fig. 2. Details of the Cooke Plains Embayment, a former extension of Lake Alexandrina. Localities of all cores taken during this study are shown. Logs of cores collected along traverses A-A', B-B' and C-C' are illustrated in the cross-sections of Fig. 3. The youngest gypsum lunette is shown at the eastern end of the Embayment. The embayment comprises the low lying swampy region shown without symbol.

Several evaporite pans occur on the embayment flats, and depending on their locality with respect to the groundwater regime and other factors, are currently depositing halite, gypsum, or Mg-calcite mud.

The former shoreline of the Cooke Plains Embayment is defined by the slope-break between the halophyte-vegetated flats and the surrounding dune system. In places, particularly along the northern shorelines, low (1–2 m) stranded cliffs can be observed cut into the calcrete surface, marking an erosional shoreline produced by wave attack under the influence of high-impact south to south-west winds. These cliffs are shown by dumpy-level traverses to have formed when water level in the lake was as much as 2.7 m above present mean sealevel.

Immediately inland from these former shorelines, particularly along the northern margin, there is evidence of prolonged occupation by aboriginal Australians. Numerous circular hearths comprising blackened calcrete cobbles associated with black soil and charcoal fragments are visible in areas where deflation has removed an unconsolidated brown siliceous sand from the irregular calcrete surface. Stone artifacts are scattered over these deflated areas and one dune drift has been eroded to expose a burial site. These remains are all obviously younger than the calcrete surface. The hearths predate the overlying brown siliceous sand which is of unknown age. Much of the occupation was probably related to the widespread humid climatic phase between about 8000 and 5000 years ago (Bowler 1971) which resulted in expanded lakes in many parts of the world. However the hearths, at least superficially, appear more ancient and could possibly be of Pleistocene age.

Present-day lakes Alexandrina and Albert have been modified by the addition of a system of barrages. These were completed in 1940 and now effectively isolate the lakes from seawater access. Prior to barrage construction a saline to brackish water environment existed in the area, which would then have been an estuary. Due to the barrages, the area is now lacustrine in character and filled with fresh water. In the ensuing discussion it will become apparent that it is not possible accurately to define from existing stratigraphic evidence whether the area was lacustrine or estuarine in character at any one time in the past. Accordingly in this paper the word lake will be used throughout, irrespective of whether or not a marine connection existed.

Methods

Stratigraphic studies of Holocene sediments of the Cooke Plains Embayment were made by a slip-hammer coring technique using P.V.C. tubing. Essentially undisturbed but somewhat compressed cores were obtained, sampling the entire Holocene sedimentary succession which ranges up to 3 m thick. Cores

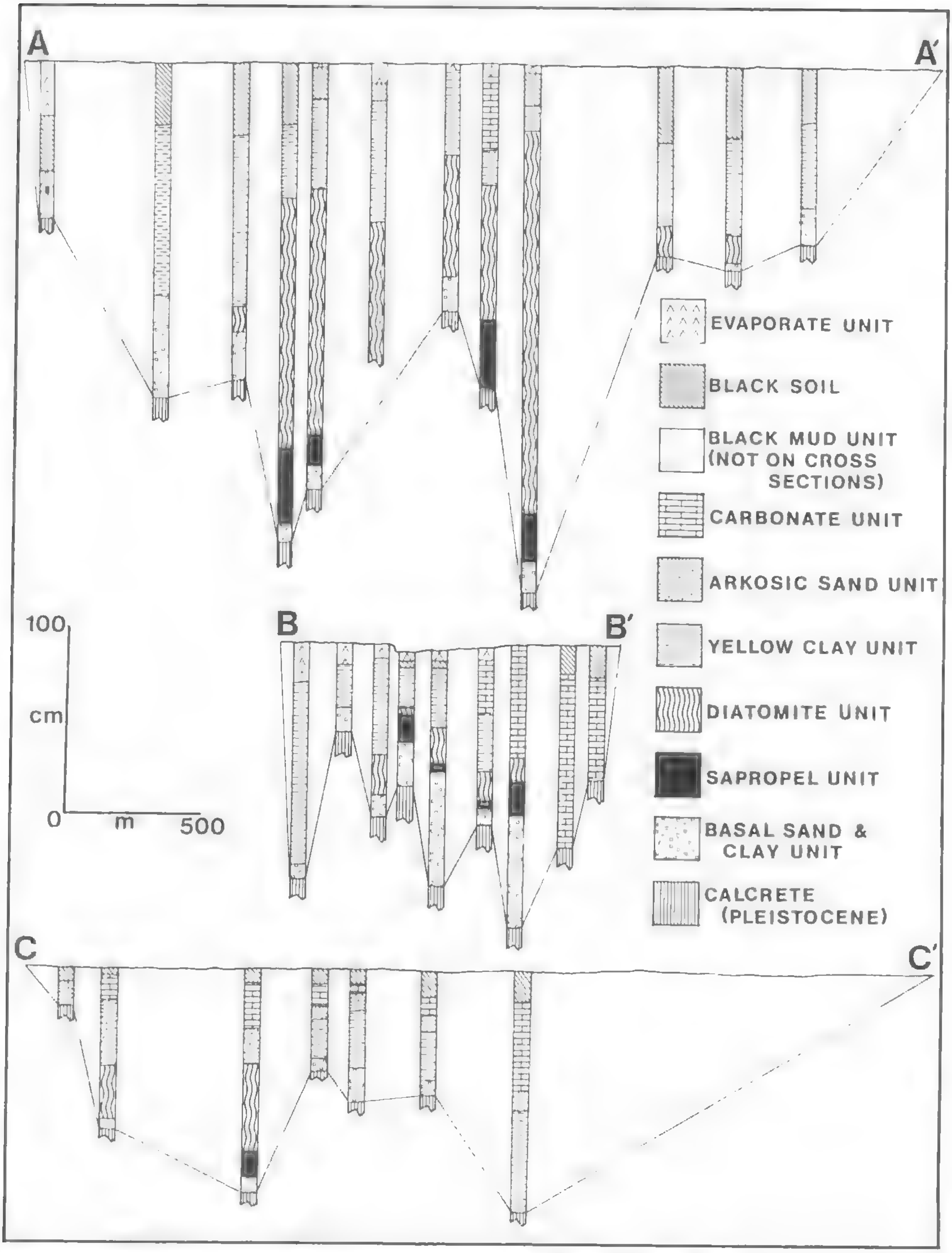

Fig. 3. Cross sections A-A', B-B' and C-C' of the Cooke Plains Embayment (See Fig. 2 for localities.) The Black Mud Unit is shown in its stratigraphic sequence in the legend, but was not intersected in these traverses.

were subsequently split in the laboratory, logged, and corrections applied for compression. Core sites were plotted on a base map (Fig. 2) using aerial photographs. Sites were subsequently levelled to *Australian Height Datum* benchmarks for the cross-sections shown in Fig. 3.

Smear slides for microscopic study and samples for X-ray diffraction and chemical analysis were taken from split sediment cores. Organic carbon content was determined using the technique of Gaudette et al. (1974).

Stratigraphy

Descriptions of stratigraphic units are presented below, beginning with the basal Holocene unit which unconformably overlies a Pleistocene calcrete soil. The units are shown in the cross-section of Fig. 3.

Basal sand and clay unit

This unit, up to 60 cm thick, comprises unconsolidated greenish clay, sand, or sandy clay, with less typical colour variations being dark grey or white. The contact with the underlying indurated calcrete is sharp. Dominant mineralogy of the coarse fraction is quartz, with lesser amounts of feldspar, halite and gypsum and traces of pyrite. The fine fraction is mainly illite and kaolinite. The unit lacks any notable fossil biota. Diatom frustules were found in only one sample.

The basal sand and clay unit is the most consistent and ubiquitous of any encountered in the Holocene section. It is found above both low and high areas of basement calcrete throughout most of the Cooke Plains Embayment (Fig. 3). It appears to be a typical diachronous transgressive sand, reworked from a regolith during expansion of ancestral Lake Alexandrina.

Sapropel unit

Stratigraphically above the basal unit in central areas of the basins lies a greenish-black, rubbery sapropel unit with a typical cheese-like fracture. It ranges to 40 cm thick. Contact with the underlying unit is gradational over about one centimetre. This sapropel is dominated by degraded remains of blue-green algae. Minor quartz, feldspar and clay are present, along with traces of gypsum, halite and calcite. Diatom frustules occur in significant numbers throughout. Palynological observations (W. K. Harris, pers. comm.) reveal a dominantly terrestrial assemblage of fossil pollen. Pollen and cuticle fragments of Chenopodiaceae (blue-bush and salt-bush group), Myrtaceae (ti-tree family), and *Casuarina,* dominate the assemblage. In addition, significant amounts of unicellular algae (*Botryococcus braunii*) and *Myriophyllum* and *Haloragis* pollen are present. The latter two species represent aquatic plants characteristic of essentially fresh-water swamps.

The sapropel unit is limited in its distribution to what clearly were deepest areas of the former embayment (Figure 3), demonstated by its restriction to central portions of the basins shown in Fig. 2. Radiocarbon dating of one sample of the sapropel shows an age of 6930 ± 150 radiocarbon years (GaK 6718).

Diatomite unit

A grey diatom-rich sediment, containing up to 70% diatom frustules, overlies the sapropel. This diatomite unit is characterized by fine internal laminations averaging one mm in thickness which are visible by X-radiography. Contact between the diatomite and sapropel units is generally gradational over several centimetres. Overall appearance and consistency of the diatomite is that of a soft, very sticky clay. Apart from diatoms, the fine fraction contains kaolinite and illite whilst the coarse fraction consists of quartz, feldspar, halite and gypsum. Diatom frustules composed of opaline silica dominate the fossil biota. Their significance as palaeo-environmental indicators will be discussed in a later section.

In terms of its distribution, the diatomite unit of the Cooke Plains Embayment is best developed in the upper reaches of the Central Basin remote from the present lake, as well as in the Upper Basin (Figs 2-3). Stratigraphically equivalent although less diatomaceous sediments occur in western portions of the Embayment nearer the lake. Like the sapropel, the diatomite unit generally is restricted to what were once deeper portions of the former extension of Lake Alexandrina, generally in centres of the basins. However it is more widespread than the sapropel, occasionally occurring directly above the basal sand and clay unit beyond the lateral extent of the sapropel (Fig. 3). This relationship suggests that the estuary or lake was still expanding during diatomite deposition.

Yellow clay unit

This unit, basically an unconsolidated yellow clay up to 1 m thick, overlies the diatomite with a gradational contact. Where the diatomite

is absent it overlies either the sapropel or the basal sand and clay unit. Typically it exhibits bright yellows, browns and rust-reds of oxidised iron. The clay-sized component of this unit, which is dominant, consists of illite along with up to 10% $CaCO_3$. The coarse fraction comprises (gypsum, halite and sand-sized quartz). Diatom frustules, the only obvious biotic remains, are sporadic in their distribution.

The yellow clay unit is areally more widespread than all underlying units with the exception of the basal sand and clay (Fig. 3), suggesting formation during the maximum Holocene extent of the lake. It is particularly well developed in the Upper Basin. Its oxidized appearance and marked local colour variability is most likely due to its stratigraphic level which lies above present-day summer groundwater table. During its deposition it may have contained significant sulphides, subsequent vadose oxidation of which may have produced the observed iron-staining. An equally feasible explanation of the staining would be that it was due to oxidation of iron sulphides carried upwards by groundwaters from underlying sulphide-rich sediments.

Arkosic sand unit

A texturally mature arkosic sand unit up to 40 cm in thickness occurs stratigraphically above or interfingers with the yellow clay unit. Contact with the clay is gradational. Like the Yellow Clay Unit it is pigmented by ferric iron. Shells of the small gastropod *Coxiella confusa* frequently occur near the top of the arkosic sand unit, indicative of progressive development of a shallow, ephemeral lake environment during the overall shoaling phase. Rare diatoms are also present at this level.

The arkosic sand unit was not detected in the Upper Basin or in portions of the Central Basin remote from present day Lake Alexandrina. However, it constitutes a large portion of the cores from the Lower Basins and western Central Basin, where it shows the previously mentioned interfingering relationship with the yellow clay unit. It therefore is considered to be in part time-equivalent to the yellow clay unit, and with it representative of the maximum stand of the lake. It appears genetically related to two now dry channels (Blind Creek, and an un-named one to the north, Fig. 2) which connect the Lower to the Central Basins. This possible relationship is supported by the fact that the arkosic sand unit seems most prominent near the inner terminations of these channels in the Central Basin. The sand has a wedge-shaped geometry which progressively thins to the east, implying a westerly origin in the form of a tidal delta or washover fan from the direction of present-day Lake Alexandrina. Progressively shoaling conditions indicated by the unit are likely due either to infilling of the estuary or to a fall in water level. Whatever the cause, the top of the unit marks the end of the transgressive phase as recorded in the sediments.

Carbonate unit

A carbonate unit up to 90 cm thick, typically a white clay-like sediment, overlies the arkosic sand or yellow clay in some areas. Its contact with underlying units is gradational over several centimetres. Fine-grained magnesian calcite is the sole carbonate mineral present. Gypsum and halite, along with minor quartz and illite, are detected on bulk X-ray diffractometer determinations. The proportion of calcite ranges between 10% and 60%. Shells of *Coxiella confusa* are common throughout the carbonate unit. This species lives in great profusion in shallow (20-30 cm) ephemeral carbonate lakes of the Lower Basins, and in similar ephemeral alkaline lakes throughout the Coorong region (von der Borch 1965). There is no doubt that the carbonate unit formed under comparable conditions, typified by winter lake filling from a rising unconfined aquifer and ensuing summer desiccation. This observation is enhanced by the fact that the carbonate unit has a sporadic occurrence. For example, cores from some areas such as the southern end of traverse B (Fig. 3) consist almost entirely of carbonate, whilst nearby cores may be essentially carbonate-free.

Generally speaking, the carbonate unit began to form during a period of lake shoreline regression. Carbonate pans were best developed around marginal areas of the Embayment, particularly on the southern sides of the Upper and Central Basins. Seepage of carbonated groundwaters from porous Pleistocene calcareous dune aquifers was best developed in these areas, providing suitable conditions for calcite to precipitate in the shallow lakes. Shallow calcite lakes of this type occur at present in the Lower Basins (Fig. 2).

Black mud unit

This unit, which is localised to the western end of Central Basin, appears to be laterally equivalent to the carbonate unit. It was not

TABLE 1.

Tabulation of maximum and average organic carbon percent of Cooke Plains Embayment stratigraphic units. Averages are based on 4-11 measurements for each unit.

Stratigraphic unit	Maximum organic C %	Average organic C %
Black soil	4.5	2.3
Black mud	5.8	2.6
Carbonate	2.8	1.1
Yellow clay	2.2	1.2
Diatomite	5.5	3.3
Sapropel	13.2	8.1
Basal sand & clay	1.4	0.9

encountered in the core traverses shown in Fig. 3. It is dominantly a black clay with prominent inclusions of crystalline gypsum and halite. Contact with the underlying unit is gradational over a few centimetres. Diatoms represent the only obvious fossil biota. The unit most likely formed in an area of permanent fresh water surrounded by the above described shallow evaporitic carbonate pans.

Evaporite unit

Uppermost unit in the Embayment, not intersected on traverses shown in Fig. 3, is an evaporite. This is a localized unit, confined to some natural evaporative pans. Thickness ranges up to a maximum of approximately 1 m. Mineralogy varies from dominantly gypsum in the Upper Basin to mainly halite in the Central Basin. "Seed" gypsum (2 mm tabular crystals) characterizes gypsum of the Upper Basin, whilst somewhat coarser (3 mm tabular gypsum crystals) are associated with the Central Basin halite. The proportion of saline evaporites and gypsum decreases in the shallow lake pans westward towards the present lake shoreline.

Organic carbon content

Organic carbon content of Cooke Plains Embayment sediments (Table 1) is typically low (0.9–1.4%) in the basal sand and clay, yellow clay and carbonate units. The black soil, black mud and diatomite units show intermediate values (2.3–3.3%) whilst the sapropel, as would be expected, has a relatively high content reaching a maximum of 13% and averaging 8.1%.

The progressive decrease in organic carbon content up-section, from the sapropel through the diatomite and yellow clay, reflects either a decrease in the amount of available organic matter, or swamping of the organic material by a sudden influx of diatoms and terrigenous clays.

Significance of the diatoms

Diatom frustules constitute the bulk of the diatomite unit and also occur in notable numbers in the sapropel. They are present in lesser quantity in the basal sand and clay, yellow clay, arkosic sand and black mud units and are absent from the carbonate and evaporite units.

Diatom species are sensitive to depositional conditions such as water temperature and salinity (Koivo 1976). From this viewpoint a preliminary examination of diatoms from the Cooke Plains Embayment sediments was carried out (D. Thomas, pers. comm.). Although additional work is required, the initial study suggests that these diatom-bearing sediments were deposited from water having a variety of salinities ranging from essentially fresh to a little less than normal marine. A general trend was detected in individual units, from fresher waters at the Lake Alexandrina end of the embayment to more saline near the eastern (inner) extremity, implying greater evaporative concentration of waters in more restricted areas. Stratigraphically, there appears to be an upward-freshening trend through the sapropel to the top of the diatomite, although these units were both deposited under relatively low salinity conditions. The yellow clay unit overlying the diatomite contains diatoms, which suggests a subsequent increase in salinity to brackish-marine. This increase is interpreted to be due to progressive restriction of the embayment during its most extensive phase by sediment infilling, and finally by chenier development. It could also be due to seawater access to the estuary at the height of the Holocene marine transgression. The carbonate unit does not contain obvious diatom frustules, possibly due to dissolution of these by alkaline water in the pans. However the black mud unit of the Central Basin has an assemblage which denotes a subsequent low-salinity phase in that locality, possibly related to a more humid climatic cycle.

Late Holocene geological history

Figure 4 illustrates generalized facies relationships of the Cooke Plains Embayment sediments. Based on textural, lithological, organic carbon and diatom data, the following late Holocene evolution is proposed.

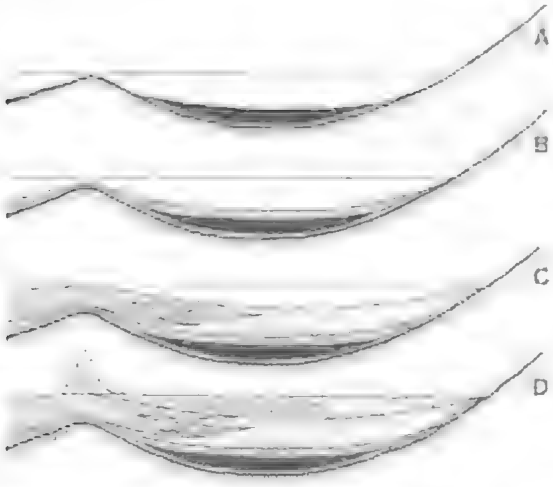

Fig. 4. Diagrammatic representation of proposed sequential development of Cooke Plains Embayment during late Holocene sedimentary infilling. A: Sapropel formation over basal sands in eutrophic freshwater lake during late Holocene humid period, approximately 6 000 years ago. B: Diatomite formation in aerated lake as deepening waters enhance the degree of connection of the Embayment with Lake Alexandrina; C: Arkosic sand (tidal delta) and yellow clay sedimentation at maximum stand of ancestral Lake Alexandrina, terminating the transgressive phase; D: Chenier formation by longshore drift sand along with regressive carbonate and evaporite sedimentation and soil formation at the end of the sedimentary cycle.

Transgressive phase

The transgressive phase of the lake is represented by the basal sand and clay, sapropel and diatomite units, along with at least the lower portions of the yellow clay and arkosic sand. These units were laid down in response to Holocene expansion of ancestral Lake Alexandrina. This expansion may have been caused in part by backing up of River Murray water in the lake due to the peak of the late Holocene marine transgression. Sealevel reached its maximum post-glacial level in the region, about 1 m above present mean sealevel, approximately 6500 radiocarbon years ago (von der Borch, 1976, ANU 1415 and 1416). The age of this maximum coincides with the previously mentioned radiocarbon date on the sapropel unit. However, it also coincides with a world-wide mid-Holocene humid period which existed 8000–5000 years ago. Elsewhere in southern Australia this period is characterized by enlarged lakes (Bowler et al. 1976). This suggests that enhanced run-off due to the higher humidity may have increased discharge of the River Murray, thereby causing or augmenting the expansion of Lake Alexandrina. Further work will be required before the exact nature of this phenomenon can be documented fully, but it may have been due to a fortuitous combination of both high sealevel and higher river discharge.

As lake water level rose, reworking of Pleistocene sandy soils overlying the calcrete surface resulted in the basal sand and clay unit. Eutrophication of the embayment waters followed. Related to this event is the sapropel unit which at least in part formed 6900 years ago (Fig. 4A). Restriction of the sapropel to deepest portions of the three basins shown in Fig. 2 suggests the possibility of stratification of lake waters at this time, resulting in oxygen depletion of bottom waters and consequent preservation and bacterial modification of organic matter in a manner similar to that described by Twenhofel & McKelvey (1941). An alternative and perhaps more acceptable explanation may be that the lake reached its maximum depth at this stage, in response to the Mid-Holocene humid period. Deeper water (several metres) and suspended River Murray sediment could have inhibited photosynthesis in all but near-surface levels, resulting in low oxygen levels and accompanying preservation of algal material on the lake floor to form the relatively pure sapropel deposit.

Shallowing of lake waters at the close of the mid-Holocene humid period may have eventually enhanced oxygenation of bottom waters, resulting in the destruction of much of the subsequently deposited organic material. Diatoms would then have been able to dominate the sediments to form the diatomite unit (Fig. 4B), whose significant clay content was possibly derived from inflow of river water with its suspended sediment load.

The widespread yellow clay and related arkosic sand units mark the maximum stand of ancestral Lake Alexandrina and the end of the transgressive phase (Fig. 4C). Water levels as high as 2.7 m above present mean sealevel are indicated by the cliffs cut in the Pleistocene calcrete around the northern embayment shoreline. The arkosic sand most likely formed as a flood-tide delta, rapidly building the embayment sediments up to water level. The simultaneously deposited yellow clay likely comprises River Murray suspended load sediment which was deposited in less energetic regions of the embayment. A progressive

increase in water salinity, detected in the diatom flora of the yellow clay unit, may have been due to relatively free access of marine waters to the lake at the peak of the post-glacial transgression, through passes in the developing Younghusband Peninsula barrier. This increase in salinity would undoubtedly have caused increased flocculation and deposition of suspended River Murray clays which, during fresher periods, would most likely have been carried in suspension out to sea.

Regressive phase

The regressive phase of the Cooke Plains Embayment is represented by the carbonate and evaporite units (Fig. 4D). The carbonate unit formed in shallow ephemeral alkaline lakes fed by seasonal groundwater inflow. As stated earlier, carbonates developed most readily along the southern margin of the embayment adjacent to the high Pleistocene dune where groundwater inflow from dune aquifers was enhanced. During shoreline regression the carbonate environment diachronously migrated to the west to localities in the Lower Basins where it is precipitating today. The evaporite unit, comprising gypsum and halite, developed in the Central and Upper Basins in areas most remote from the present Lake Alexandrina and in a region of seasonal groundwater discharge and evaporation. Like the carbonates, evaporites are also forming at the present day in some areas.

The black mud unit, with its freshwater diatom flora, resembles the organic-rich mud which is being trapped around reed-beds in present day freshwater Lake Alexandrina. It exists in the Central Basin near the top of the stratigraphic sequence, where it occurs in place of the carbonate and evaporite units. Such a relationship is most easily explained by a short-lived period of increased humidity which resulted in the formation of a freshwater swamp in the Central Basin. Carbonates and evaporites could have continued to form in pans marginal to this swamp. A period of relatively high stream discharge 3500–1800 years ago has been suggested by Williams (1973) to explain some aspects of alluvial fans stratigraphy in the Lake Torrens region of South Australia. This humid period may correlate with the formation of the black mud unit. Alternatively, its formation may have been synchronous with a period more humid than the present one, centred at about 1000 years ago. At this time Lake Keilambete in western Victoria had a water level significantly higher than the present level (Bowler et al. 1976).

Chenier and lunette formation

The two cheniers (Fig. 2) across the mouth of the Cooke Plains Embayment are built from siliceous sands provided by long-shore transport within the lake. They overlie calcitic muds which are thought to be correlative with the carbonate unit. The older, inner chenier was constructed when water level was slightly higher than the present lake level. The outer bar is probably still forming. The fact that the inner chenier sits on a clayey unit which contains carbonate similar to the carbonate unit described earlier suggests it to be a relatively recent feature, formed following most of the sedimentation in the Embayment. A period of lake level stillstand or increased storm activity may have existed to enable littoral transport to construct the sand spit. Following this, a relatively rapid but slight (tens of cm) drop in the lakewater to its present level occurred.

The two well-defined gypsum lunettes at the eastern extremity of the embayment are difficult to date on existing evidence. Bowler (1971) notes double lunette dunes around playa lakes throughout southeastern Australia, and provides convincing evidence that they formed by wind deflation of evaporite pans during drying stages following humid climatic cycles. If the lunettes are correlative with those described elsewhere by Bowler (1971), then they are of the order of 25 000 years old, formed during the regional humid to arid climate changes at that time. On the other hand it is possible that at least the lunette nearest the lake may be considerably younger, and related to Holocene sedimentation in the Cooke Plains Embayment. Obviously further work is required to clarify this matter.

Regional correlations

Stratigraphic studies and surveying of core sites to mean sealevel (using Australian Height Datum benchmarks) imply that a major interconnected body of water existed in the area up to 5000 or 6000 years ago, during the time of maximum level of Lake Alexandrina. The water body in question extended from lakes Albert and Alexandrina and their stranded flats, via the north and south lagoons of the Coorong, to regions now occupied by stranded ephemeral carbonate lakes adjacent to the southern extremity of the Coorong Lagoon.

Cores taken from all of these widely separated areas contain a sapropel unit in deepest portions of the basins (Taylor & Poole 1931; von der Borch 1965, 1976, Milne[1] 1973, Plush[2] 1974, Lock[3] 1974, Dunstan[4] 1976). Radiocarbon dates (GaK 6007 and 6008) made on sapropel from below a carbonate mud sequence in two of the alkaline lakes adjacent to the southern Coorong Lagoon, give ages of 8000 ± 470 and 6600 ± 210 radiocarbon years respectively, the last of which is equivalent in age to that of at least a portion of the Cooke Plains Embayment sapropel. Quite clearly a major freshwater lake system existed over the area during the mid-Holocene humid period, which ended 5000 years ago. This lake presumably received its water from the River Murray. At the onset of less humid conditions subsequent to 5000 years ago the lake level fell. As a result the marginal areas became stranded and in some areas evolved into discrete groundwater-fed alkaline or saline evaporite lakes, interrupted by a temporary return to freshwater conditions possibly a thousand years ago. Such a climatic evolution is consistent with that proposed by Bowler et al. (1976) from studies of Lake Keilambete in western Victoria.

Acknowledgments

Valuable discussions relevant to this study were held with Pat De Decker, Keith Walker and Mike Geddes, of the Department of Zoology, University of Adelaide.

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A REVISED KEY TO THE AUSTRALIAN GENERA OF MATURE MAYFLY (EPHEMEROPTERA) NYMPHS

BY P. J. SUTER

Summary

A revised, illustrated generic key to mature nymphs of the Ephemeroptera (mayflies) of Australia is presented. A résumé of diagnostic characters of the five families represented in Australia is also given, and a list of the 19 genera described from Australia is included.

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Summary

SUTER, P. J. (1979) A Revised Key to the Australian Genera of Mature Mayfly (Ephemeroptera) Nymphs. *Trans. R. Soc. S. Aust.* 103(3), 79-83, 31 May, 1979.

A revised, illustrated generic key to mature nymphs of the Ephemeroptera (mayflies) of Australia is presented. A résumé of diagnostic characters of the five families represented in Australia is also given, and a list of the 19 genera described from Australia is included.

Introduction

Although the Ephemeroptera, or mayflies, are abundant in the Australian freshwater environment, their classification below the level of Family is unreliable. The majority of the systematic study on this Order has been concerned with the adult stage, with approximately 70 species being described. Of these species only 33 have been associated with their respective nymphs. This situation, although similar to that found in the rest of the world (Edmunds & Allen 1966), is anomalous in that nymphs are by far the longest living stage, and they are often abundant in benthic samples from permanent freshwater habitats. The inability to identify animals abundant in the benthos limits the amount of information that is available on the benthic community.

Williams (1968) recognised this problem and provided a key to the genera of Ephemeroptera nymphs, noting that some difficulties would occur in its use. After examining numerous collections of nymphs and adults, from all parts of Australia, a revision of Williams' key to genera has been prepared. Comments and criticisms from biologists upon this revision will enable further improvements to be made, resulting in reliable identification.

There has been debate about the classification of this Order, especially of the families Baetidae and Siphlonuridae. Riek (1970) placed the two groups as subfamilies Siphlonurinae and Baetinae in the Baetidae. In 1973, Riek refers to the Siphlonuridae and Baetidae as separate families. Recent reviews of the phylogeny of the Ephemeroptera (Edmunds 1975; Edmunds, Jensen & Berner 1976) also consider these as separate families. This classification (used also by Williams 1968) has been maintained in this paper. The three other families recognised in Australia to date are Leptophlebiidae, Ephemerellidae, and Caenidae.

Four genera in the Leptophlebiidae have been described from adults only and no formal description of nymphal material has been made. These genera are, *Atalomicria* Harker, *Kirrara* Harker, *Thraulophlebia* Demoulin, and *Ulmerophlebia* Demoulin. Of these all except *Thraulophlebia* have been included in a study of adult and nymphal morphology and phylogeny by Tsui & Peters (1975), and nymphs of two (*Atalomicria* and *Kirrara*) have been illustrated but not described by Riek (1970). Therefore, these genera cannot be incorporated in this key, but a mention of the characteristics which distinguish them, as illustrated by Riek, is included.

Atalomicria nymphs "have conspicuous, greatly elongated maxillary palpi" (Riek 1970) which extend well beyond the front of the head, and in *Kirrara* "the abdominal gills have ventral lobes which combine to form a large suction disc" (Riek 1970).

A résumé of the five families of Australian mayflies is included here. The number of species mentioned refers to published material. There are undoubtedly numerous as yet unde-

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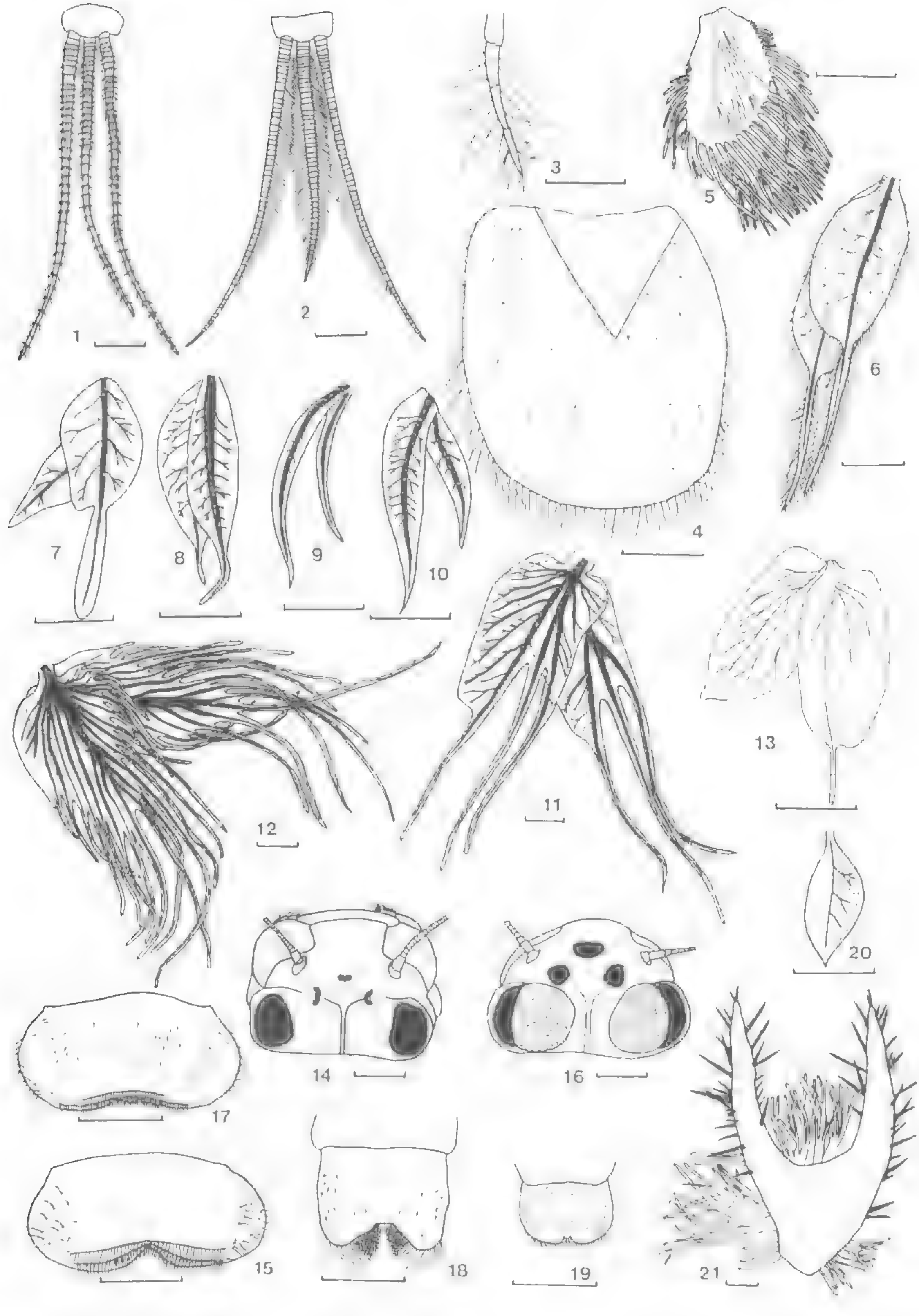
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scribed species (cf. Riek 1970), but these cannot be included until formal descriptions are published.

Key to the genera of mature Australian mayfly nymphs

1. Head prognathous, thorax and abdomen dorso-ventrally flattened, caudal filaments with whorls of setae at apex of each segment (Fig. 1); Leptophlebiidae, Caenidae, and Ephemerellidae . . . 2
   Head hypognathous, thorax cylindrical (abdomen may be dorso-ventrally flattened), inner margin of lateral caudal filaments and both lateral margins of central filament fringed with long setae (Fig. 2) Siphlonuridae and Baetidae . . . 7
2. Prominent double row of spines dorsally on abdomen, 5 pairs of sub-ovate gills on abdominal segments 2-6; Ephemerellidae . . . *Austremerella*
   Without double row of dorsal spines on abdomen, gills on abdominal segments 1-5, 1-6 or 1-7 . . . 3
3. Seven pairs of paired gills inserted laterally on abdomen, sometimes linear, lanceolate, or broad and multidigitate; Leptophlebiidae . . . 4
   Five or 6 pairs of gills, first a short single filament (Fig. 3), second enlarged, forming an elytriform gill cover (Fig. 4), covering remaining pairs which bear long tracheal filaments (Fig. 5); Caenidae . . . *Tasmanocoenis*
4. Gills broadly ovate with an apical filament on each lamina, long fine setae covering gill surface (Fig. 6), legs with long fine setae, 2 tusk-like projections arising from front of head present or absent . . . *Jappa*
   Gill surface without long fine setal covering, legs without long fine setae, head without frontal tusks . . . 5
5. Gills linear-lanceolate, sometimes broadly so (Figs. 7, 8, 9, 10) . . . 6
   Gills broad, apex of each gill lamella sub-subdivided with one, 3 or multi tracheal filaments (Figs. 11, 12, 13) . . . *Atalophlebia*
6. Postero-lateral spines on abdominal segments 4-9, spines progressively larger posteriorly, mandibles and maxillae laterally exposed producing broad angular head (viewed dorsally) (Fig. 14) with frontal width greater than width at posterior margin, labrum with deep U-shaped median notch (Fig. 15) . . . *Atalophlebioides*
   Postero-lateral spines on abdominal segments 6-9, spines progressively larger posteriorly, mandibles and maxillae held beneath head such that front of head is rounded (Fig. 16) with frontal width narrower than width at posterior margin . . . *Atalonella*
7. Hind corners of abdominal segments not produced into backward pointing spines, head hypognathous, labrum with square median notch; Baetidae . . . 8
   Hind corners of abdominal segments produced into backward pointing spines, labrum entire or with broad median U-shaped notch, head hypognathous; Siphlonuridae . . . 12
8. Gill lamellae double on abdominal segments 1-6, seventh gill single, hind wing pad absent . . . *Cloeon*
   Gill lamella single on abdominal segments 1-7 . . . 9
9. Labrum square, with deep V-shaped median notch, with pair of teeth at apex of indentation (Fig. 18), tarsal claws long and slender, half as long as tarsi . . . *Centroptilum*
   Labrum oval, with shallow square median notch (Fig. 19), tarsal claws short, less than one quarter tarsal length . . . 10
10. Gills pointed with trachea on one half of median line only (Fig. 20) . . . *Bungona*
    Gills ovoid with trachea branched over entire lamella . . . 11
11. Metathoracic wing pads absent in mature nymphs . . . *Pseudocloeon*
    Metathoracic wing pads present . . . *Baetis*
12. Four pairs of gills, first pair elytriform covering last 3 pairs . . . *Tasmanophlebia*
    Seven pairs of gills present . . . 13
13. Gills deeply bifid and strongly spinose (Fig. 21), thorax strongly humped . . . *Coloburiscoides*
    Gills lamellate, not deeply bifid or spinose, thorax weakly humped . . . 14
14. Gills lamellate, first 2 pairs small, with tufts of fibrils situated posteriorly near base, mandibles with long slender incisors, maxillae without long curved apical spines (carnivorous) . . . *Mirawara*
    Gills simple lamellate structures; mandibles with single broad incisor, maxillae without long curved apical spines . . . *Ameletoides*

Figs. 1-21. 1, caudal filaments of *Atalonella*; 2, caudal filaments of *Baetis*; 3, 4, 5, first, second and third gill respectively, of *Tasmanocoenis tillyardi*; 6, third gills of *Jappa*; 7, 8, 9, gills of *Atalonella*, 10, gill of *Atalophlebiodides*; 11, third gill of *Atalophlebia australis*; 12, third gill of *A. australasica*; 13, third gill of *A. longicaudata*; 14, dorsal view of head of *Atalophlebiodes* (♀), 15, labrum of *Atalophlebioides*, 16, dorsal view of head of *Atalonella* (♀), 17, labrum of *Atalonella*, 18, labrum of *Centroptilum*; 19, labrum of *Baetis*; 20, gill of *Bungona narilla* (after Harker 1957); 21, gill of *Coloburiscoides*. Scale lines 0.5 mm

Family LEPTOPHLEBIIDAE

Nymphs large, slender, dorso-ventrally flattened with prognathous head, maxillary and labial palps 3-segmented. Abdominal segments 1-7 bear lateral gill; three long caudal filaments with whorls of short setae at apex of each segment.

The nymphs are found in most permanent freshwater habitats from standing waters to fast flowing streams.

The Leptophlebiidae is the dominant mayfly family in Australia with 43 described species in eight genera. Of the 43 species only 16 are described from both adult and associated nymphs. A list of the genera and the number of described species is included, while the number of species which have both adult and nymph descriptions are distinguished by parentheses.

Atalophlebia Eaton 1881 18 (10) species described.

Atalonella Needham & Murphy 1924 7(3) species described.

Atalophlebioides Phillips 1930 9 (3) species described.

Atalomicria Harker 1954 2 (0) species described.

Jappa Harker 1954 2 (1) species described.

Kirrara Harker 1954 3 (0) species described.

Thraulophlebia Demoulin 1955 1 (0) species described

Ulmerophlebia Demoulin 1955 1 (0) species described.

Family CAENIDAE

Small brown nymphs, dorso-ventrally flattened, head prognathous, thorax robust. Abdomen short with gills on segments 1-5 or 1-6. First segment with pair of single filamentous gills, secod segment with an enlarged elytriform gill cover, covering remaining pairs which bear long tracheal filaments. Hind corners of abdominal segments produced into small backward pointing projections, and there are three caudal filaments with whorls of short setae at apex of each segment.

The nymphs are found on the undersurface of rocks and wood on the bottom of ponds and standing pools, as well as in slow to moderately fast flowing streams.

Only one genus is recorded in Australia.

Tasmanocoenis Lestage 1930, 3 (2) species described.

Family EPHEMERELLIDAE

Nymphs lacking gills from one or more of segments 1-7. Only a single nymph and a few adult females have been recorded from Australia (Riek 1963). The generic characteristics of *Austremerella* are after Riek (1963) "Paired abdominal gills on segments 2-6, the first pair not modified into opercula. A double row of tubercles on all abdominal segments. Femora and tibiae flattened with a median longitudinal ridge on the upper surface. Vertex of head with a pair of tubercles." (Riek 1963).

Only one genus is recorded in Australia.

Austremerella Riek 1963, 1 (1) species described.

Family BAETIDAE

Nymphs small and slender with cylindrical thorax, and slightly dorso-ventrally flattened abdomen. Head hypognathous, labrum with square median notch on anterior margin. Gills on abdominal segments 1-7, plate like, hind corners of abdominal segments usually not produced into backward pointing projection, if so, only small projections present. Abdomen with three caudal filaments, inner margins of lateral filaments and both lateral margins of central filament fringed with long setae.

The nymphs are common in riffle sections of rocky streams but may be found "amongst the water-weeds of ponds, dams and slow flowing streams and backwaters" (Riek 1970).

There are 12 described species in five genera.

Baetis Leach 1815 5 (3) species described.

Centroptilum Eaton 1869 1 (1) species described.

Cloeon Leach 1815 4 (1) species described.

Pseudocloeon Klapálek 1905 1 (0) species described.

Bungona Harker 1957 1 (1) species described.

Family SIPHLONURIDAE

Nymphs with cylindrical bodies, head hypognathous, labrum entire, or with broad median U-shaped notch on anterior margin. Gills on abdominal segments 1-4 or 1-7. Hind corners of abdominal segments produced into large backward pointing projections. Abdomen with 3 caudal filaments, inner margin of lateral filaments and both lateral margins of central filament fringed with long setae.

The nymphs are usually strong swimmers found in "rapidly flowing, clear cold water

streams, but some species occur in small subalpine lakes" (Riek 1970) and backwaters of lowland streams.

There are 10 species described in four genera.

Ameletoides Tillyard 1933 1 (1) species described.

Tasmanophlebia Tillyard 1921 3 (3) species described.

Coloburiscoides Lestage 1935 3 (2) species described.

Mirawara Harker 1954 3 (1) species described.

Acknowledgments

I would like to thank Professor W. D. Williams who encouraged me to revise the generic key, and to Dr J. Bishop for critically reading the draft manuscript, and for his encouragement in its preparation.

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THREE NEW SPECIES OF PROPALLENE (PYCNOGONIDA: CALLIPALLENIDAE) FROM AUSTRALIAN WATERS

BY DAVID A. STAPLES

Summary

Three species of the genus Propallene are described; P. saengeri sp. nov. from Queensland, P. cyathus sp. nov. and P. vagus sp. nov. from Victoria. Ecological notes are provided for two species indicating that both utilize ocean currents as a means of dispersal. The occurrence of cement gland ducts on segments additional to the femur is recorded for the first time in the genus.

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Summary

STAPLES, D. A. (1979) Three new species of *Propallene* (Pycnogonida; Callipallenidae) from Australian waters. *Trans. R. Soc. S. Aust.* **103**(4), 85-93, 31 May, 1979.

Three species of the genus *Propallene* are described; *P. saengeri* sp. nov. from Queensland *P. cyathus* sp. nov. and *P. vagus* sp. nov. from Victoria. Ecological notes are provided for two species indicating that both utilize ocean currents as a means of dispersal. The occurrence of cement gland ducts on segments additional to the femur is recorded for the first time in the genus.

Introduction

In his revision of the Genus *Propallene*, Stock (1975) recorded its distribution as Japan, southeastern Asia, southern and southeastern Africa, Madagascar and Sierra Leone. Three new species described here increase the total to ten and establishes a new record from Australian waters. The Australian material is recorded from the shallow waters of two diverse regions: the tropical waters of Queensland in the north, and the southern temperate waters of Victoria. *Propallene saengeri* was collected using a Van Veen Grab during benthic surveys at the mouth of the Calliope River, Gladstone, Queensland, for the Queensland Electricity Generating Board; *P. cyathus* was collected using S.C.U.B.A. during an offshore benthic survey for the Latrobe Valley Water and Sewerage Board southwest of Seaspray on the Ninety Mile Beach, and *P. vagus* was collected using S.C.U.B.A. in the vicinity of Port Phillip Heads. Institutions in which type material has been lodged are referred to by the following abbreviations: National Museum of Victoria (N.M.V.); Tasmanian Museum and Art Gallery (T.M.); Queensland Museum (Q.M.); Western Australian Museum (W.A.M.); Institute of Taxonomic Zoology, (Zoölogisch Museum, Amsterdam (Z.M.A.).

Family: CALLIPALLENIDAE

Propallene cyathus sp. nov.

FIG. 1A–P, FIG. 2A–B

Specimens Examined; Holotype: ♂ (ovig.) N.M.V. K43, 1 km offshore, southwest of Seaspray, Bass Strait, Vic.: depth 13 m, coll. J. E. Watson 15.iiv.77. *Allotype:* ♀ N.M.V. K44, 1 km offshore, southwest of Seaspray, Bass Strait, Vic.: depth 13 m, coll. N. W. Watson 16.xi.77. *Paratypes:* W.A.M. 1 ♂ 78/579, 1 ♂ 78/580, 1 ♂ 78/581, 1 ♀ 78/582, 1 ♀ 78/583, 1 ♀ 78/584; 3 ♂ 3 ♀ Q.M. S205; 3 ♂ 3 ♀ T.M. J1353; 3 ♂ 3 ♀ N.M.V. K45; 3 ♂ 3 ♀ Z.M.A. Pa2838; 245 ♂, 87 ♀, 32 juveniles lodged in private collection of author.

Description: Trunk segmented, arched, lateral processes separated by less than own diameter. In male, lateral processes longer than trunk diameter. In female, lateral processes equal to, or longer than, diameter of trunk. Each lateral process bears row of 2–3 (or 4) very small spinules on mid-dorsal surface; distally each process bears further 2–3 slightly larger spinules. Abdomen implanted between 4th pair of lateral processes and directed somewhat ventrally, tapering distally. Ocular tubercle low, rounded, eyes indistinctly pigmented; lateral sense organs present.

Chelifores: Scape one-segmented; both fingers curved, gaping when closed, movable finger with 6–10 teeth, immovable finger with 5–8 teeth, palm with several long setae.

Palps only present in male; oriented ventrally, consisting of short unarmed basal part and robust claviform distal segment. Length of distal segment 6–7 times its proximal diameter and expands dorsally to maximum width of slightly less than 2,5 times proximal diameter at about one-half its length. Terminally this segment bears dense lateral fringe of curved

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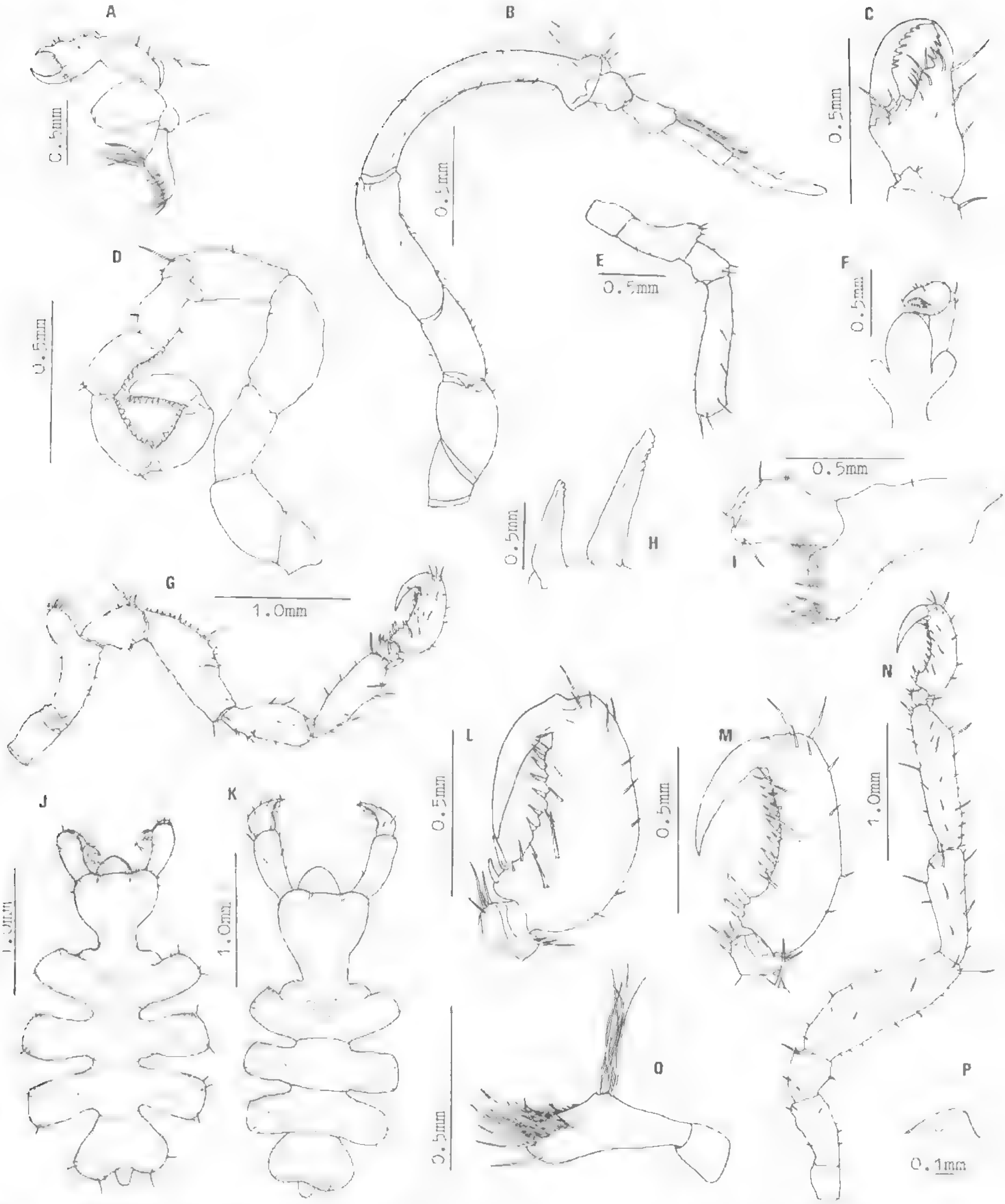

Fig. 1. *Propallene cyathus* sp. nov. A, Cephalic region, lateral view, male; B, Oviger, male; C, Chela, male; D, Oviger, female; E, Proximal segments, leg 4, juvenile male; F, Cephalic region, ventral view, juvenile male; G, Leg 4, male; H, Propodal heel spines, female; I, Coxa 2, 3, leg 4, male; J, Trunk of male, dorsal; K, Trunk of female, dorsal; L, Distal leg segments, male; M, Distal leg segments, female; N, Leg 3, female; O, Palp, male; P, Ocular tubercle, female.

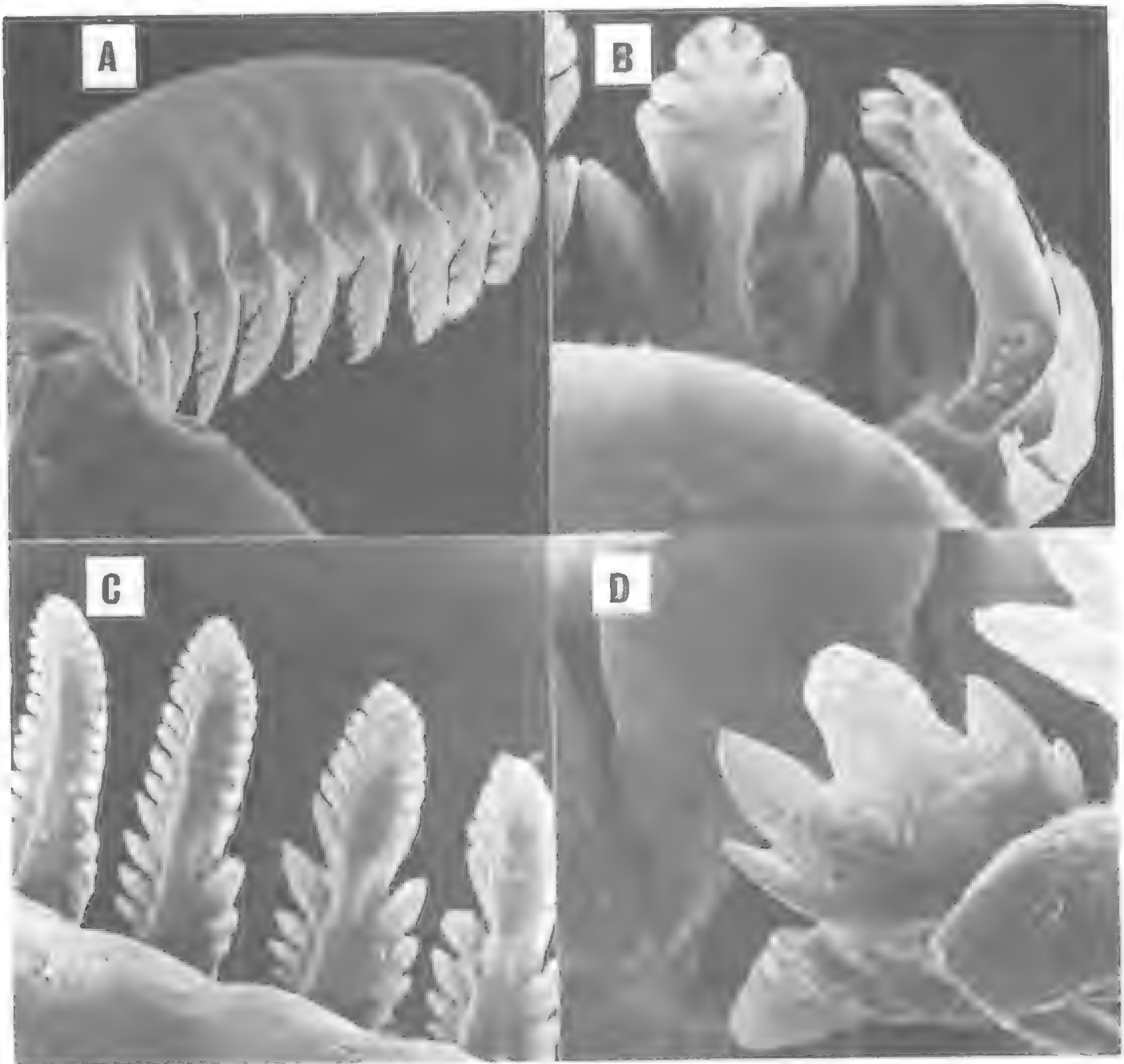

Fig. 2. A, *Propallene cyathus* sp. nov. Compound oviger spines on tenth segment of ♂ oviger (x880). B, *Propallene cyathus* sp. nov. Terminal compound oviger spines on tenth segment of ♀ oviger (x2400). C, *Propallene vagus* sp. nov. Compound oviger spines 5-8 on ninth segment of ♂ oviger (x1100). D, *Propallene saengeri* sp. nov. Terminal compound oviger spine on tenth segment of ♂ oviger (x2200) (S.E.M. photographs).

setae which progressively increase in length along distal margin. Overall formation of these setae resemble a scoop or ladle-like appearance. Specific name alludes to this feature. A group of very long setae, approximately 5 times proximal diameter of palp, originates from mid dorsal region.

Oviger 10-segmented, without terminal claw. In male, segment 5 longest; segments 3, 4 and 5 armed with recurved spinules; distally fifth segment bears setiferous apophysis and well developed process opposite. Compound spines polymorphous (Fig. 2, A), proximal spines bear 7–9 lateral teeth on either side, basal 1 or 2 pairs of teeth heavily sclerotized; distal spines shorter and more robust, terminal spine particularly broad and bears 2–3 very heavily sclerotized basal teeth on either side (Fig. 2, B). Compound spine formula varies considerably between individuals. Spine formula occurring on segments 7–10 in holotype is 8:11:10:14. Segment 7 armed with 3 very long setae reaching beyond segment 8. Female oviger lacking recurved spinules, segment 4 longest, setiferous apophysis and opposing process lacking on segment 5. Compound spine

formula of allotype for segments 7–10 is 9:11:9:11; shape of compound spines as in male.

Measurements of oviger segments (mm): 1 ♂ .2, ♀ .16; 2 ♂ .25, ♀ .28; 3 ♂ .27, ♀ .2; 4 ♂ .59, ♀ .32; 5 ♂ .9, ♀ .25; 6 ♂ .14, ♀ .18; 7 ♂ .17, ♀ .24; 8 ♂ .25, ♀ .23; 9 ♂ .2, ♀ .21; 10 ♂ .18, ♀ .2.

Legs of male: Femur is longest segment and bears 15–22 cement gland tubules ventrally, rows of setae present on both tibiae; tibia 2 longer than tibia 1. Second coxa approximately 3 times as long as its proximal diameter. Well developed processes situated on second coxae of fourth pair of legs; this process bears lateral fringe of curved setae like that found on distal palp segments. Process usually swollen, however, in some specimens distal surface confined within setiferous fringe may be collapsed, giving concave appearance. Propodus heavy, strongly curved, heel with two (or three) terminally crenulate spines. Number of heel spines inconstant. Sole armed with 5–7 spines. Terminal claw slender; auxiliaries absent. Genital pores not evident in male. In female, femur more swollen than that of male, propodus moderately slender; genital pores present on ventral surface of second coxae of all legs. In both sexes fourth pair of legs shorter than remaining pairs.

Measurements of holotype and allotype (mm): length trunk (frontal margin of cephalic segment to tip of abdomen) ♂ 2.35, ♀ 1.98; length cephalon ♂ 1.08, ♀ 1.05; greatest width cephalon ♂ .65, ♀ .61; length proboscis ♂ .59, ♀ .53; greatest width proboscis ♂ .38, ♀ .39; width across second lateral process ♂ 1.25, ♀ .98; diameter trunk ♂ .35, ♀ .33; length scape ♂ .48, ♀ .42; length palp ♂ first seg. .13, second seg. .5. Third leg: coxa 1 ♂ .45, ♀ .3; coxa 2 ♂ .59, ♀ .51; coxa 3 ♂ .4, ♀ .28; femur ♂ 1.25, ♀ 1.28; tibia 1 ♂ .98, ♀ .93; tibia 2 ♂ 1.10, ♀ 1.15; tarsus ♂ .12, ♀ .1; propodus ♂ .6, ♀ .54; claw ♂ .36, ♀ .35.

Remarks: The new species is clearly distinguished from all congeners by the shape and setation of the palps and also in possession of the well developed processes on the 2nd coxae of the 4th pair of legs in the male. With the exception of *P. stocki* Fage (in which the 2nd palp segment is slightly dilated), the 2nd palp segment in all species is slender, frequently narrowing to a constriction at 30–50% of its length. In *P. cyathus* the proximal portion is inflated dorsally with no constriction evident. The tall mid dorsal setae found on the 2nd palp segment and the large coxal processes in the male are not present in any other member of the genus. The only other species bearing a heavy propodus is *P. crassimanus* Stock.

Propallene cyathus was found in vast numbers amongst colonies of the arborescent bryozoan *Vittaticella fusca*? (McGillivray) during a benthic survey conducted in November 1977 southwest of Seaspray for the Latrobe Valley Water and Sewerage Board. Examination of 347 adult individuals showed an extremely high percentage of fertile specimens; 92.9% of the males were ovigerous and 96.8% of the females were gravid. Only three specimens of *P. cyathus* were recorded from two previous surveys of the same station in March and August, 1977. In March 1977, one ovigerous male and two juvenile males were collected. No specimens were recorded from the latter survey. Such a high percentage of fertile specimens in November suggests a cyclic breeding pattern, and the complete absence of specimens just four months earlier, may indicate a migratory response to their reproductive activity. Hydrological studies by Newell (1961) indicate a seasonal reversal of current patterns in this region, and it is probable that the extent of migration is largely dependent on the Bass Strait current system. In many instances specimens were heavily encrusted with the epiphytic coralline alga *Heterodermu* sp.

Propallene vagus sp. nov.

FIG. 3A–N, FIG. 2C

Specimens Examined: Holotype: ♂ N.M.V. K46, 1 km southwest of Port Phillip Heads, Vic.; depth 30 m, coll. D. A. Staples 6.vi.1976. *Allotype:* ♀ (grav.) N.M.V. K47. *Paratypes:* 1 ♂ (sub adult); 8 ♀ N.M.V. K48, 1 ♂ (sub adult), 2 ♀, private collection of author.

Description: Trunk segmented, strongly arched in male; neck more slender than in female; lateral processes longer than diameter of trunk and separated by less than their own diameter. Each lateral process bears dorsally 2, 3 (or 4) small distal spines, and 1 or 2 smaller spinules more proximally. Abdomen short, expanded at base, inclined ventrally. Ocular tubercle conical, more acute in male; four indistinct eyes; lateral sense organs present.

Chelifores scape one segmented bearing several scattered setae; both fingers curved, gaping when closed, movable finger with 6–7 teeth, immovable finger with 4–6 teeth, palm with several long setae.

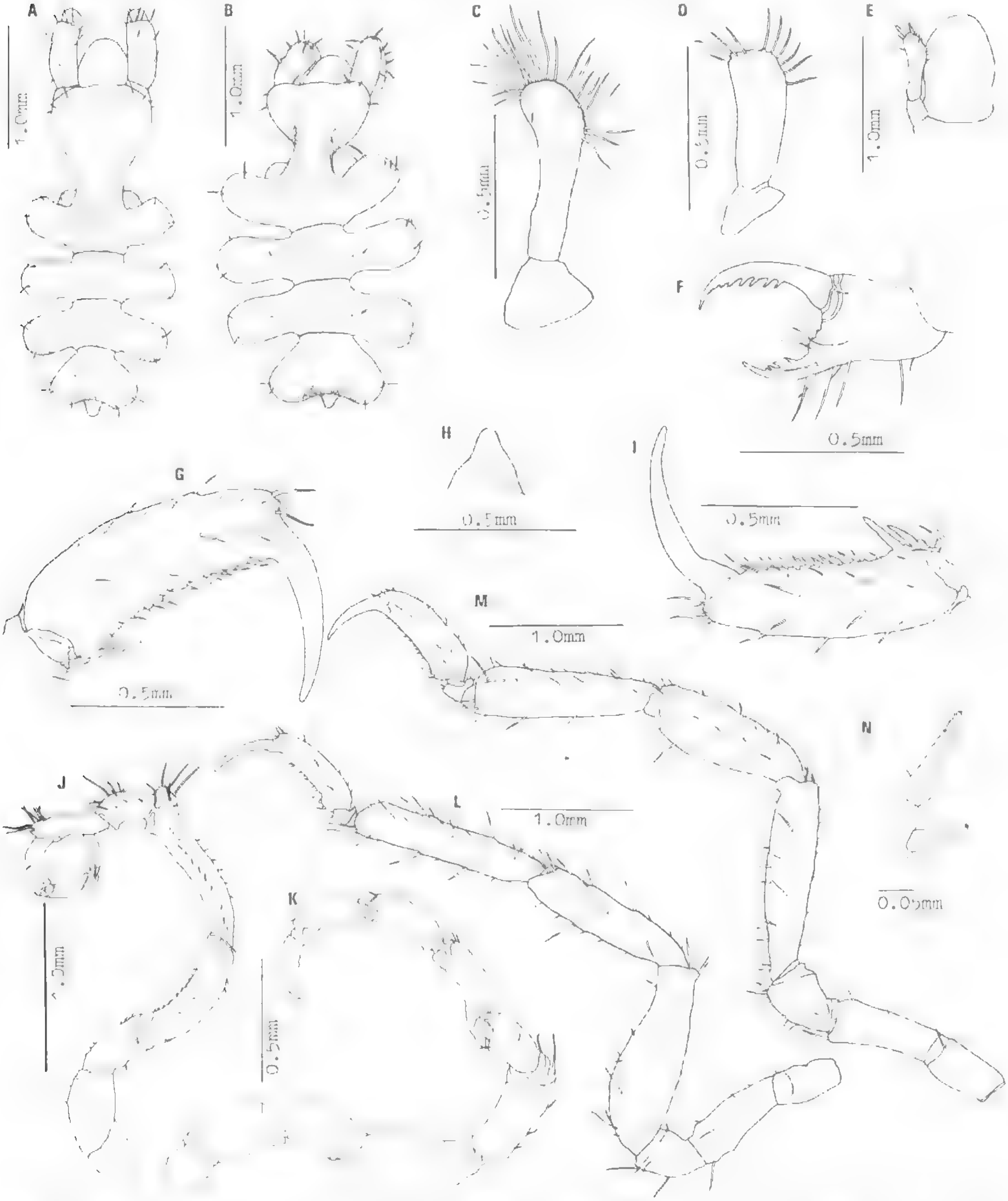

Fig. 3. *Propallene vagus* sp. nov. A, Trunk of female, dorsal; B, Trunk of male; dorsal; C, Palp, male: D, Palp, sub-adult, male; E, Palp and proboscis, male, ventral view; F, Chela, male; G, Propodus, male; H, Ocular, male; K, Oviger, female; L, Leg 3, female; M, Leg 3, male; N, Propodal heel spines, male.

Palps present only in male; 2-segmented, basal segment short and unarmed, second segment curved and swollen distally, a slight constriction present at about 30% of its length, measuring approximately 5½ times its proximal width. Armed distally with fringe of 20–30 setae.

Oviger of male: segment 10 of holotype damaged (terminal spines lacking), segment 5 longest, distally bearing setiferous lobe and

opposing pointed process, recurved spinules present on segments 3, 4 and 5; compound spines polymorphous (Fig. 2, C), proximal spines bear 12–16 pairs of lateral teeth, more or less of equal size; distal spines bear four pairs of heavily sclerotized basal teeth, terminal spine broader and shorter than remainder. Compound spine formula variable between specimens, spines on segments 7–10 of holotype according to formula 15:12:11:(12?). Segments 6 and 7 bearing several setae distally. Female oviger segment 4 longest, segment 5 without distal lobe and opposing process, recurved spinules absent; compound spine formula of allotype 13:12:11:13; shape of compound spines as in male.

Measurements of oviger segments (mm): 1 ♂ .18, ♀ .19; 2 ♂ .39, ♀ .33; 3 ♂ .38, ♀ .32; 4 ♂ .68, ♀ .57; 5 ♂ .90, ♀ .47; 6 ♂ .31, ♀ .33; 7 ♂ .38, ♀ .38; 8 ♂ .28, ♀ .34; 9 ♂ .32, ♀ .28; 10 ♂ damaged, ♀ .29.

Legs of male: Femur longest segment, tibia 2 longer than tibia 1, rows of setae present on both tibiae. Second coxa approximately three times proximal width. Propodus robust; moderately curved, heel with two spines in which crenulation is generally indistinct, sole armed with 10–11 spinules. Femur with 5–8 femoral cement glands. Genital pores not evident. Auxiliary claws absent. Female propodus less robust than in male; distal propodal heel spine more elongated than in male; femur swollen; genital pores present on second coxae of all legs.

Juvenile: Distinguishing features from adult male are smaller size and more compact and less setiferous palps.

Measurements of holotype and allotype (mm): length trunk (frontal margin of cephalic seg. to tip of abdomen), ♂ 2.98, ♀ 2.83; length cephalon ♂ 1.28, ♀ 1.63; greatest width cephalon ♂ .93, ♀ .99; length proboscis ♂ .76, ♀ .88, greatest width proboscis ♂ .55, ♀ .65; width across second lateral process ♂ 1.35, ♀ 1.3; diameter of trunk ♂ .43, ♀ .41; length scape ♂ .68, ♀ .73; length palp ♂ first seg. .19, second seg. .54. Third leg: coxa 1 ♂ .55, ♀ .55; coxa 2 ♂ .88, ♀ .75; coxa 3 ♂ .48, ♀ .43; femur ♂ 1.43, ♀ 1.64; tibia 1 ♂ 1.28, ♀ 1.3; tibia 2 ♂ 1.4, ♀ 1.45; tarsus ♂ .15, ♀ .13; propodus ♂ .8, ♀ .7; claw ♂ .48, ♀ .5.

Remarks: Superficially this species resembles *P. cyathus* sp. nov. in the general shape of the trunk and in the distal fringe of long setae on the second palp segment. It differs clearly, however, in the absence of the coxal process on the 4th pair of legs, in the lower number of femoral cement gland ducts, and in the shape of the terminal palp segment, which also lacks the long mid-dorsal setae. With the possible exception of *P. similis* inadequately described from one male specimen by Barnard (1955) the combination of less than 10 cement gland ducts restricted to the femur, the 2nd coxa less than 4 times its basal diameter, lateral processes longer than the trunk diameter (and separated by less than their own diameter) distinguishes *P. vagus* from all congeners.

In the absence of further records of the male of *P. similis*, and Stock's inability to locate the holotype (Stock 1974), morphological data on this species are still inadequate. I am satisfied, however, that the following features are sufficient to justify the specific status of *P. vagus*: larger size (e.g., ♀ leg 3 of *P. similis* is 4.79 mm, that of *P. vagus* 7.45 mm), proportionately longer and more setiferous second palp segment (e.g., Barnard illustrates the second segment as approximately 7 times its basal diameter, with a small group of setae distally; *P. vagus* 5½ times, and with a dense fringe of long setae distally), stronger male propodus and the wider intervals between lateral processes. The specimens were first sighted tumbling over a sandy substrate in response to the strong tide flow at Port Phillip Heads. Because of their thigmotactic nature most specimens had attached themselves to small fragments of drifting detritus, the only identifiable piece of which was a portion of a colony of the arborescent bryozoan *Cornucopina grandis* (Busk).

The specific name, *vagus* (wandering) alludes to the situation in which the specimens were observed when collected.

The collection comprised only three males, two of which are sub-adult, and eleven females. The single mature male had remnants of cement adhering to the fifth oviger segment indicating that eggs had been carried. Of the 11 females, 10 were gravid, and the low number, or complete absence of eggs in some legs, suggested that eggs had recently been deposited.

Propallene saengeri sp. nov.

FIG. 4A–L, FIG. 2D

Specimens Examined: Holotype: ♂ (uVig.) Q.M. S195 Stn 6.5 1 soft mud, Calliope River Queensland 3 km upstream from mouth.

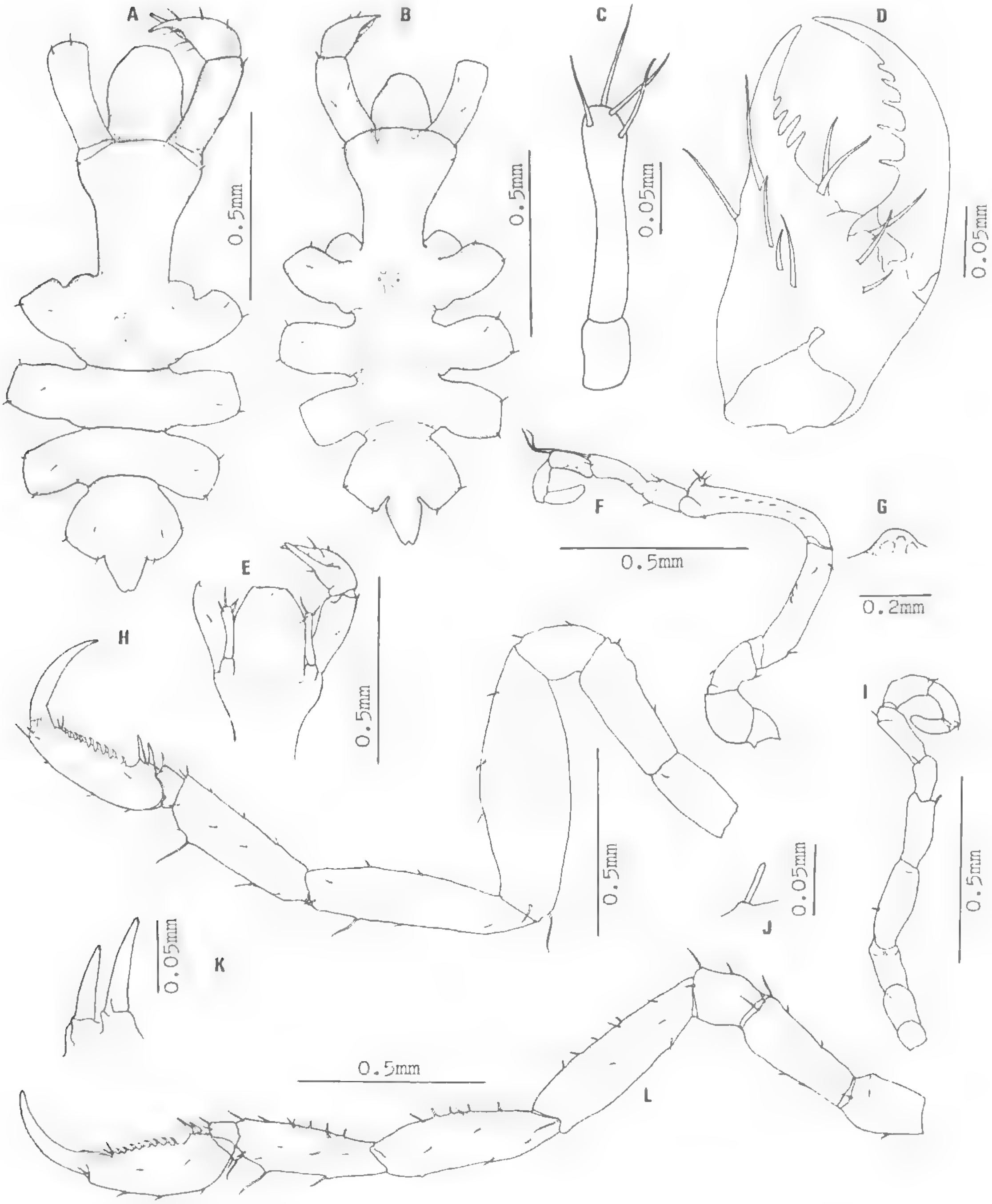

Fig. 4. *Propallene saengeri* sp. nov. A, Trunk of female, dorsal; B, Trunk of male, dorsal; C. Palp, male; D. Chela, male; E, Cephalic region. male ventral; F, Oviger, male; G, Ocular tubercle. female; H, Leg 3. female; I, Oviger, female, J. Cement gland duct. male; K, Propodal heel spines, female; L, Leg 3, male.

depth 2.1 m, coll. Queensland Electricity Generating Board, May 1976. *Allotype:* ♀ (grav.) Q.M. S196 Stn 8.11.5 soft mud, Calliope River, depth 2 m, coll. Q.E.G.B., Nov. 1976. *Paratypes:* 1 ♀ (grav.) Q.M. S197 Stn 7.11.1 fine mud with some detrital matter, Calliope River, Aug. 1976, 1.5 km upstream, depth 1.5 m, coll. Q.E.G.B. Aug. 1976. 1 ♀ (grav.) N.M.V. K49 Stn 7.11.4 coarse sand, mouth of Calliope River 1.5 km upstream, depth 4.8 m, coll. Q.E.G.B. Aug. 1976. 1 ♀ (grav.) Stn 8.11.5 soft mud, Calliope River, depth 2 m, coll. Q.E.G.B. Nov. 1976, lodged with Queensland Electricity Generating Board. 1 ♀ (grav.) Stn 8.9.5 soft mud, Calliope River, depth 2 m, coll. Q.E.G.B. Nov. 1976, lodged in author's private collection

Description: Trunk segmented, lateral processes shorter than diameter of trunk and separated by less than their own diameter. Each lateral process armed with one small seta situated almost mid dorsally, and 2 or 3 similar setae distally. Abdomen short, well developed for the genus, directed somewhat ventrally. Ocular tubercle: low, rounded, eyes indistinctly: pigmented lateral sense organs present.

Chelifores: scape 1-segmented: palm of chela armed with several setae. Immovable finger with four teeth, movable finger with five teeth. Both fingers curved, gaping when closed.

Palp only present in male: 2-segmented, basal segment short and unarmed. Distal segment approximately 3.5 times as long as basal segment and slightly greater than six times its own proximal diameter, armed distally with four long setae. No constriction evident.

Ovigers: In male, segment 5 longest. Distally this segment bears setiferous lobe with small and inconspicuous opposing tooth-like process. Recurved spinules present on segment 3, 4 and 5. Segment 7 bears 2 long setae reaching beyond segment 8. Compound spines on segments 7–10 according to formula 10:10:8:9. Compound spines polymorphous, proximal spines bear 7–9 lateral teeth of about equal size on either side. Distal spines bear two pairs of heavily sclerotized basal teeth; terminal spine broad and bears 2 large basal teeth on either side (Fig. 2 D). In female, segment 4 is longest, segment 5 without distal lobe and process, recurved spinules absent. Compound spine formula 12:10:9:11.

Measurements of oviger segments (mm): 1 ♂ .05, ♀ .04; 2 ♂ .12, ♀ .12; 3 ♂ .14, ♀ .14; 4 ♂ .29; ♀ .21; 5 ♂ .37, ♀ .19; 6 ♂ .07, ♀ .10; 7 ♂ .12, ♀ .17; 8 ♂ .11, ♀ .12; 9 ♂ .11, ♀ .10; 10 ♂ .10, ♀ .12.

Legs: Femur is longest segment; tibia 1 longer than tibia 2, sparsely setose; second coxa approximately 3.5 times as long as its proximal diameter; propodal heel with two terminally crenulate spines; sole with 8–10 spines. Auxiliary claws absent. Cement gland tubules present on femur, tibia 1 and tibia 2 of the male. Four tubules on tibia 1 of all legs, 4–6 femoral tubules and 3–4 on tibia 2. Genital pores not visible. In female, femur swollen to accommodate ovaries. Genital pores present on ventro-distal surface of second coxae of all legs.

Measurements of holotype and allotype (mm): length trunk (frontal margin cephalon to tip of abdomen) ♂ 1.1, ♀ 1.2; length cephalon ♂ .51, ♀ .6; greatest width cephalon ♂ .31, ♀ .35; length proboscis ♂ .27, ♀ .35; greatest width proboscis ♂ .2, ♀ .22; width across second lateral process ♂ .61, ♀ .62; diameter trunk ♂ .21, ♀ .24; length scape ♂ .22, ♀ .29; length palp ♂ first seg. .04, second seg. .15. Third leg: coxa 1 ♂ .17, ♀ .21; coxa 2 ♂ .32, ♀ .32; coxa 3 ♂ .15, ♀ .16; femur ♂ .49, ♀ .65; tibia 1 ♂ .45, ♀ .55; tibia 2 ♂ .36, ♀ .46; tarsus ♂ .06, ♀ .05; propodus ♂ .35, ♀ .38; claw ♂ .25, ♀ .28.

Remarks: The occurrence of cement gland ducts on leg segments additional to the femur is a notable feature previously recorded only in *Nymphon* and *Ascorhynchus*. In the absence of any mention of cement glands in descriptions of *P. similis* and *P. stocki*, it is not known whether this occurrence in *P. saengeri* is unique in the genus. Cement glands in all other members of the genus are confined to the femur.

The new species differs from *P. stocki* in the nature of the second palp segment which is longer (greater than 6 times as long as its basal diameter) and bears a fringe of long setae distally. In *P. stocki* the second palp segment is unarmed, and about 3 times as long as wide. *Propallene similis* differs from *P. saengeri* in: larger size (e.g., leg 3 ♀ *P. similis* 4.79 mm, terminal claw excluded; leg 3 ♀ *P. saengeri* 2.78 mm, terminal claw excluded); higher number of teeth on the fingers of the chela; the strong constriction of the second palp segment (very slight in *P. similis*), and in having tibia 2 longer than tibia 1. In view of the variability noted by Stock (1975) in *P. longiceps*, however, the significance of this latter feature is uncertain.

The new species was named for Dr P. Saenger who forwarded the specimens for examination.

Diagnosis of Genus Propallene

Inclusion of the new species necessitates amendment to Stock's (1975) diagnosis of *Propallene*.

Trunk well segmented. Ocular tubercle in posterior part of cephalic segment. Abdomen small, implanted somewhat ventrad. Proboscis roughly of type D'. Scape 1-segmented. Palp only present in male. Oviger 10-segmented (♂, ♀). Segment 5 (♂) with distal apophysis and opposite distal hook-like or conical process. Compound spines present, in 1 row, proximal and distal spines on each segment very dissimilar in shape (♂, ♀). No terminal oviger claw (♂, ♀). Cement glands (♂) opening through numerous (5–22) short ducts on ventral surface of either femur alone or femur, tibia 1 and tibia 2. Propodal heel spines often crenulated, but frequently indistinct; no auxiliary claws.

Geographic distribution of Propallene

P. kempi (Calman 1923), southeastern Asia; *P. longiceps* Bohm (1879b), Japan; *P. similis* Barnard (1955), southern Africa; *P. ardua* Stock (1975b), eastern Africa. *P. crassimanus* Stock (1959), southern and southeastern Africa; *P. stocki* Fage (1956), Sierra Leone; *P. crinipes* Stock (1968a). Straits of Malacca; *P. saengeri* sp. nov., northeastern Australia; *P. vagus* sp. nov., southeastern Australia; *P. cyathus* sp. nov., southeastern Australia.

Acknowledgments

I should like to express my gratitude to Dr P. Saenger, Queensland Electricity Generating Board; Mrs J. E. Watson, National Museum of Victoria, and the Latrobe Valley Water & Sewage Board, for entrusting their collections to me. Thanks are also due to Dr B. J. Smith, National Museum of Victoria for his assistance and advice. Dr B. F. Stratford and Mr P. G. Hollis, University of Melbourne for permission to use the scanning electron microscope and Mr P. E. Bock, Royal Melbourne Institute of Technology for his identification of the Bryozoa. I also wish to acknowledge the assistance given by the Science and Industry Endowment Fund, C.S.I.R.O.

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REVISION OF NOMENCLATURE FOR PALAEOZOIC INTRUSIVES OF THE MOUNT PAINTER PROVINCE, SOUTH AUSTRALIA

BY GRAHAM S. TEALE

Summary

The term Mudnawatana Granite has been used to describe two large bodies of Palaeozoic granite in the Mount Painter Province of South Australia. The two intrusive bodies are petrographically and geochemically distinct.

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Summary

TEALE, GRAHAM S. (1979) Revision of nomenclature for Palaeozoic intrusives of the Mount Painter Province, South Australia. *Trans. R. Soc. S. Aust.* **103**(4), 95-100, 31 May 1979.

The term Mudnawatana Granite has been used to describe two large bodies of Palaeozoic granite in the Mount Painter Province of South Australia. The two intrusive bodies are petrographically and geochemically distinct.

It is suggested that the term Mudnawatana Granite be changed to Mudnawatana Tonalite and applied only to the pluton in the Mt Babbage Block. It is proposed that the other large pluton which intrudes the Mt Painter Block be termed the British Empire Granite. A third, previously unmapped Palaeozoic intrusive type is designated the Gordon Springs Granodiorite.

Chappell & White (1974) have used geochemical, isotopic, mineralogical and textural criteria to distinguish granite types with a basic to intermediate igneous protolith ("I-type") from those with a metasedimentary protolith ("S-type"). The Mudnawatana Tonalite and Gordon Springs Granodiorite do have many characteristics indicative of "I-type" granitoids; the British Empire Granite, however, exhibits most of the characteristics ascribed to "S-type" granitoids.

Introduction

Previous mapping within the Mt Painter Province of South Australia (Coats *et al.* 1969) has separated a "Younger Granite Suite" from the older (Carpentarian) metamorphic basement complex. This "Younger Granite Suite" includes minor biotite and muscovite pegmatites, aplites, potassium-rich pegmatitic granite and albitites but is predominantly composed of the Mudnawatana Granite (Bowes 1953). The term Mudnawatana Granite was first applied by Bowes (1953) to the pluton in the Mt Babbage Block (Fig. 1) but has since been extended by Coats & Blissett (1971) to include two bodies of granite that intrude the central part of the Mt Painter Block (Fig. 1).

According to Bowes (1953) the Mudnawatana Granite in its type locality is a medium-grained, equigranular rock consisting of plagioclase (An_{26}), quartz, biotite and microcline. Using a modal analysis he categorised the intrusion as an "adamellite on the border of this group close to granodiorite". Coats & Blissett (1971) also used the term granodiorite for the intrusives contained within the Mt Painter Block and classified them with

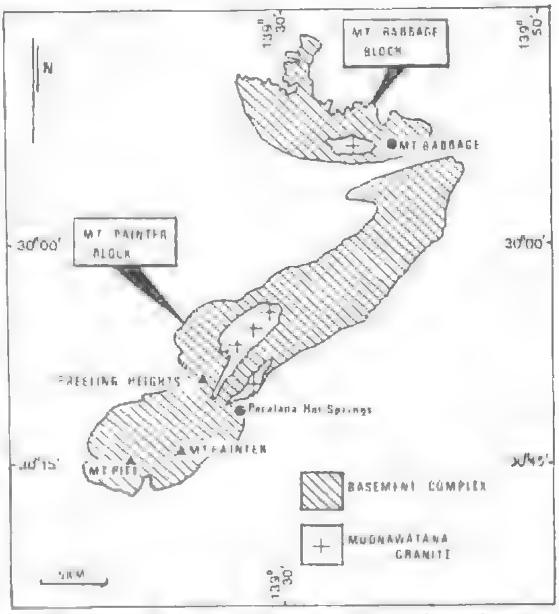

Fig. 1. Mt Painter Basement Complex showing occurrences of the Mudnawatana Granite as mapped by Coats *et al.* (1969) (areas not shaded represent Adelaidean and younger sediments).

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the type Mudnawatana Granite because of their "similar composition, texture and grain size". Neither Bowes (1953) nor Coats & Blissett (1971) used chemical data for their classifications of the intrusives.

This paper presents the results of a re-examination of these leucocratic intrusive rocks. Three distinct intrusive types can be recognised on geochemical and petrographic data and a revision of present nomenclature is recommended. The terms tonalite, granodiorite and granite as used here conform to the recommendation of the I.U.G.S. Subcommission on the Systematics of Igneous rocks (Streckeisen 1976).

Field Relationships

The Gordon Springs Granodiorite occurs as small stocks and crosscutting dykes (Fig. 2) which intrude augen gneiss and sillimanite gneiss in the Radium Creek area and migmatitic gneiss in the Paralana Hot Springs area. It is similar in colour and texture to the Mudnawatana Tonalite although usually it is more fine-grained. No contact metamorphic features are evident.

In the upper reaches of Radium Creek, the granodiorite, at its type locality, intrudes a zone of strongly lineated sillimanite gneiss which was developed during the last pre-Adelaidean deformational event. The weak foliation evident in the granodiorite cannot be attributed to this deformation and it is suggested that the fabric is a result of the later Delamerian orogeny; the implication is that the granodiorite was emplaced prior to the Delamerian orogeny. Dating of the Gordon Springs Granodiorite, using the Rb/Sr isotopic technique, is currently being undertaken.

Field relationships of the Mudnawatana Tonalite have been adequately described by Bowes (1953) and Coats & Blissett (1971). The tonalite is intrusive into deformed Carpentarian granitoids and has caused minor recrystallisation of pre-existing gneissic textures. No other contact metamorphic phenomena have been observed. The weak foliation present implies that it has been deformed after its emplacement.

The British Empire Granite has intruded as large semi-conformable sills which dip shallowly towards the west. The non-foliated, and therefore probably post-Delamerian intrusive, has numerous pegmatitic apophyses, all of which occur along the western margin (or roof) of the intrusive. According to Coats & Blissett (1971) the granite contains abundant xenoliths and rafts of Freeling Heights Quartzite; they suggest that the granite is pre-orogenic on the grounds of its apparent structural repetition in the Paralana Hot Spring area. There are, however, no granitoids similar to the British Empire Granite in that area.

It is proposed that the type Mudnawatana Granite be reclassified as the Mudnawatana

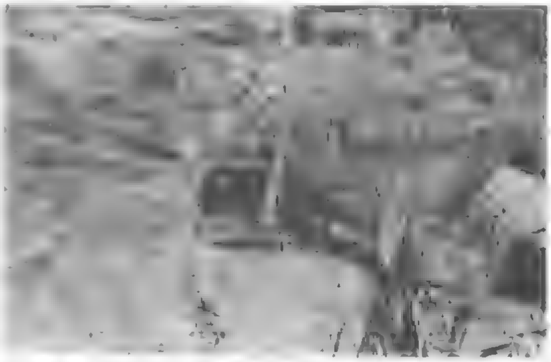

Fig. 2. Dyke of Gordon Springs Granodiorite cutting highly deformed Precambrian augen gneiss in Radium Creek (hammer is 0.7 m in length).

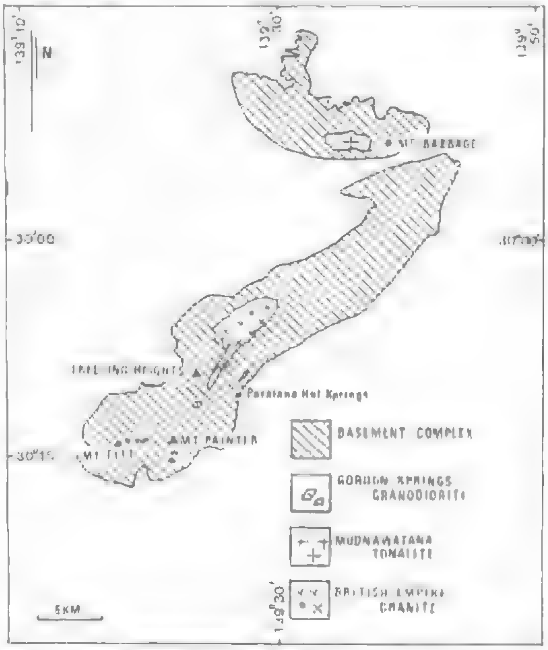

Fig. 3. Mt Painter Basement Complex with revised nomenclature for occurrences of Palaeozoic intrusives (areas not shaded represent Adelaidean and younger sediments).

Tonalite and a new name, the British Empire Granite, be given to the central intrusive body to the northeast of Freeling Heights (Fig. 3). In the southern Mt Painter Block previously unrecognised intrusives occur as small stocks and dykes and it is proposed that these be called the Gordon Springs Granodiorite (Fig. 3).

Petrography

The Gordon Springs Granodiorite

The Gordon Springs intrusive is a fine grained, equigranular, grey biotite granodiorite which is restricted in outcrop to the southern part of the Mt Painter Block (Fig. 3). The granodiorite consists of sodic andesine (An_{32}), microcline, biotite and quartz with accessory magnetite, monazite, apatite and rare rutile and zircon. Plagioclase (~1.5 mm) is complexly zoned and twinned and has been deformed and recrystallised along its grain boundaries. Quartz exhibits undulose extinction and sub-grain development. Apatite (0.05 mm) and zircon are usually associated with biotite whereas monazite occurs randomly distributed throughout the rock. Some larger apatite grains (up to 0.3 mm) occur as inclusions in plagioclase. Biotite composition can be used to characterise the different plutons, using wt % Al_2O_3 and the ratio 100 Mg/Mg + Fe. Biotite in the Gordon Springs Granodiorite is red brown in colour and contains 16.5 wt % Al_2O_3 and has a 100 Mg/Mg + Fe of 56 (mean of 4 analyses). Muscovite occurs in the more corundum normative variants, with secondary muscovite and rare sub-aluminous amphibole formed during the Delamerian event.

In Radium Creek, approximately 1 km upstream from its junction with Arkaroola Creek, there is a hornblende-bearing variant of the Gordon Springs Granodiorite. The rock is slightly coarser than the normal Gordon Springs intrusive and has a grain size of approximately 2 mm. Brown-green hornblende is found as single grains throughout the rock and has a 100 Mg/Mg + Fe of 61. Hornblende and biotite comprise approximately 8% of the mode with calcic oligoclase, barium rich micro-perthitic K-feldspar and quartz accounting for the remainder. Biotite is yellow-brown and has a low Al_2O_3 value (12.4 wt %) and a 100 Mg/Mg + Fe of 72. Although monazite is the dominant accessory phase in the hornblende-free variety of the Gordon Springs Granodiorite it is not present in this hornblende-bearing type. The accessory phases in this small stock are sphene and allanite (0.08 mm) with rare zircon associated with biotite. Acicular apatite grains are found in both biotite and plagioclase with magnetite occurring as discrete grains scattered throughout the rock.

The Mudnawatana Tonalite

The Mudnawatana Tonalite as described petrographically by Bowes (1953) is a weakly foliated, medium grained granitoid which in thin section exhibits deformed and in places recrystallised quartz, feldspars and biotite. It contains calcic oligoclase, quartz, microcline and biotite with rare zircon and apatite. Zircon is found in biotite and is responsible for the numerous pleochroic haloes that are present. Apatite is also confined mainly to biotite and is usually acicular. No monazite has been observed. Magnetite is found as granules within biotite with no magnetite grains in the matrix. Plagioclase is more sodic than the Gordon Springs Granodiorite plagioclase and is also complexly twinned and zoned. The average size of plagioclase grains is 1.5 mm; however, some plagioclase crystals up to 1.5 cm have been observed. Plagioclase cores are usually replaced by aggregates of muscovite, calcite and kaolinite.

The British Empire Granite

The British Empire Granite is a fine to medium grained, light coloured, muscovite-bearing alkaline granite which consists of abundant muscovite (up to 5 mm), sodic plagioclase, microcline, quartz and minor biotite, garnet (~0.3 mm), apatite, fluorite and rare magnetite. No zircon, monazite, allanite or sphene have been recorded. Plagioclase compositions range from almost pure albite to An_{c}, with an average composition of An_{6}. The plagioclase shows no zoning optically but is slightly zoned chemically. The K-feldspar is a low-soda microcline with Na_2O content varying slightly but always less than 1 wt %. It is commonly rimmed by albite, especially at microcline-microcline grain boundaries. Garnet when present is manganese rich (23-25 wt %) and slightly zoned. Neither the Mudnawatana Tonalite nor the Gordon Springs Granodiorite contain garnet. Muscovite is present as large (~2 mm) bladed grains which can contain up to 1.4 wt % F. The rather ragged biotite is aluminous (18.5 wt %) and has a 100 Mg/Mg + Fe of 32. Apatite is not

associated with biotite in this granite and it usually forms large (up to 1 mm) grains interstitial to quartz and feldspars.

Geochemistry and Discussion

The Gordon Springs Granodiorite is quite distinct from both the British Empire Granite and the Mudnawatana Tonalite in that it contains very high Ba and Sr values and also has higher values for TiO_2, CaO, MgO, Total Fe and Zr (Table 1). It has a K/Rb ratio (~120) intermediate between the British Empire Granite and the Mudnawatana Tonalite and has a Rb/Sr ratio closer to the tonalite than the granite. The hornblende-bearing variety of the granodiorite has a slightly higher K/Rb ratio (154) and is the only diopside normative Palaeozoic granitoid (Table 1); all other intrusives are corundum normative to varying degrees. The hornblende-bearing intrusive also contains magnetite and sphene as the dominant accessory phases in common with other "I-type" plutons (Chappell & White 1974; O'Neil *et al.* 1977). The hornblende-absent granodiorite, which is the more common variant, contains monazite as the dominant accessory phase, a feature not usually characteristic of "I-type" plutons (Chappell & White 1974). A noticeable distinction between the Gordon Springs Granodiorite and the Mudnawatana Tonalite is the absence of monazite in the latter. The granodiorite has between 0.3% and 1.4% normative corundum and mol. $Al_2O_3/(Na_2O + K_2O + CaO)$ values of less than 1.1.

The Mudnawatana Tonalite has lower values of P_2O_5, TiO_2, K_2O, MgO, Total Fe, Rb and Zr and a higher value of Na_2O than the Gordon Springs Granodiorite. Its K/Rb ratio (275) is much higher than any other pluton and it has the lowest Rb/Sr ratio of all the Palaeozoic granitoids (Table 1). Its initial Sr^{87}/Sr^{86} ratio of .7045 ± .0012 is so low as to preclude all but an insignificant contribution of old crustal material.

The "I-type" character of the Mudnawatana Tonalite and the Gordon Springs Granodiorite is not marked; however, the mol. $Al_2O_3/(Na_2O + K_2O + CaO)$ values of less than 1.1, the high Na_2O/K_2O ratios (Fig. 4) and the low initial Sr^{87}/Sr^{86} ratio of the Mudnawatana Tonalite are all indicative of "I-type" plutons (Chappell & White 1974). Their position on the Ab-An-Or diagram (Fig. 5) indicates that they are much higher temperature melts than the "S-type" British Empire Granite.

The British Empire Granite has higher SiO_2, Rb and Nb and lower MgO, TiO_2, CaO, Zr, Sr and Ba than the Mudnawatana Tonalite and the Gordon Springs Granodiorite. It has extremely low K/Rb ratios (Table 1) and very high Rb/Sr ratios. There is a chemical inhomogeneity within the mass and variation diagrams exhibit a large scatter, a feature

TABLE 1

Chemical analyses of the intrusives under discussion. 1. British Empire Granite. 2. Spessartine garnet-bearing variant of the British Empire Granite. 3. Gordon Springs Granodiorite. 4. Hornblende-bearing variant of the Gordon Springs Granodiorite and 5. Mudnawatana Tonalite.

	1	2	3	4	5
SiO_2	75.42	77.08	68.70	70.05	71.93
Al_2O_3	13.95	13.70	16.21	15.63	15.64
Fe_2O_3*	0.90	0.67	2.35	2.00	1.27
MnO	0.04	0.11	0.01	0.04	0.04
MgO	<0.01	0.01	1.27	0.95	0.42
CaO	0.61	0.42	2.85	2.75	2.37
Na_2O	4.08	5.76	4.38	4.67	5.33
K_2O	4.07	1.32	2.73	3.10	1.92
TiO_2	0.06	0.03	0.42	0.33	0.15
P_2O_5	0.12	0.21	0.11	0.10	0.04
L.O.I.	0.60	0.63	0.77	0.37	0.63
TOTAL	99.84	99.94	99.79	99.99	99.74
Sr	37	4	845	774	483
Zr	28	4	228	180	99
Ba	143	5	1480	1183	310
Rb	413	234	167	167	58
Nb	37	38	15	13	8
Rb/Sr	11.16	58.50	0.20	0.22	0.12
K/Rb	82	47	136	154	275
Plagioclase An. Content (core)	7	2	32	24	26
100 Mg/Mg + Fe of biotite	32	N.P.	56	72	N.D.
C.I.P.W. Norm					
Q	34.71	37.82	24.29	23.37	27.47
C	2.01	2.54	1.13	—	0.58
OR	24.05	7.80	16.13	18.32	11.35
AB	34.52	48.74	37.06	39.52	45.10
AN	2.24	0.71	13.42	12.53	11.50
DI WO	—	—	—	0.19	—
EN	—	—	—	0.11	—
FS	—	—	—	0.07	—
HY EN	0.02	0.02	3.16	2.26	1.05
FS	0.91	0.84	1.74	1.52	1.14
MT	0.33	0.25	0.86	0.72	0.46
IL	0.11	0.06	0.80	0.63	0.28
AP	0.28	0.49	0.26	0.23	0.09
OR	39.55	13.63	24.22	26.03	16.70
AB	56.77	85.13	55.64	56.16	66.38
AN	3.69	1.24	20.15	17.18	16.92

* Total iron as Fe_2O_3.

N.P. Biotite not present in the rock.

N.D. Not determined.

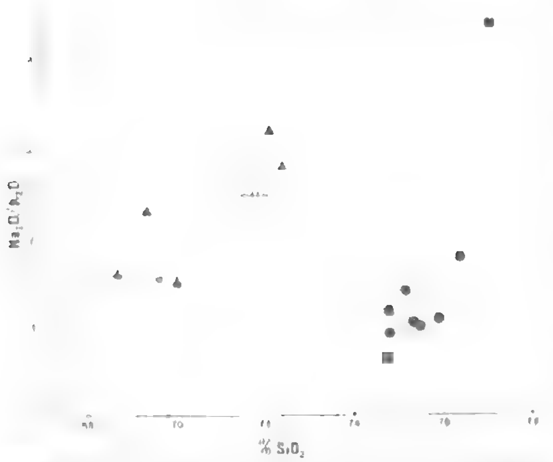

Fig. 4. Plot of Na_2O/K_2O versus SiO_2 showing the separation of the "I-type" Mudnawatana Tonalite (open triangles) and Gordon Springs Granodiorite (filled triangles) from the "S-type" British Empire Granite (filled circles).

Fig. 5. Ab-An-Or plot of the intrusives under discussion. (Symbols as for fig. 4.)

which is typical of "S-type" plutons (Chappell & White 1974). The mol. $Al_2O_3/Na_2O + K_2O + CaO)$ values are all greater than 1.1 and all analysed samples are greater than 1.7% corundum normative; both features that are common to "S-type" granitoids. The high value of SiO_2 and the low to negligible content of MgO, CaO and TiO_2 suggest that it is close to a minimum melt composition. The positions of the analysed samples on the Ab-An-Or diagram (Fig. 5) verify this. The initial Sr^{87}/Sr^{86} ratio of .7591 ± .0146 (J. A. Cooper pers. comm.) is indicative of "S-type" plutons, albeit extraordinarily high.

Biotites from the British Empire Granite have exceptionally high octahedral Al (0.9-1.0 atoms) whereas octahedral Al in biotites from the Gordon Springs Granodiorite are from 0.30-0.35 atoms. Biotite from the hornblende-bearing variant of the granodiorite has less than 0.1 atom of octahedral Al. Albuquerque (1973) has noted that the composition of biotite is probably a strong indicator of the peraluminous character of the granite. O'Neil *et al.* (1977) show that biotites from "S-type" granites of the New England Batholith have octahedral Al in excess of 0.6 atoms.

In Fig. 6 analysed samples of the granitoids under discussion have been plotted in terms of Al-Na-K, Ca and Fe + Mg. All samples of the British Empire ("S-type") Granite fall in the field of plagioclase + muscovite + Mn-rich garnet, whereas all but one of the Mudnawatana Tonalite and Gordon Springs Granodiorite ("I-types") samples fall into the field of plagioclase + biotite or plagioclase + biotite + hornblende. The separation of the tonalite and granodiorite from the granite can also be observed in Fig. 4 with the more siliceous British Empire Granite having overall lower Na_2O/K_2O ratios, with the tonalite and the granodiorite having higher Na_2O/K_2O ratios.

Conclusions

From petrographic and geochemical evidence it is suggested that the term Mudnawatana Granite be changed to Mudnawatana Tonalite and be applied only to the Palaeozoic intrusive mapped by Bowes (1953) and Coats & Blissett (1972) in the Mt Babbage Block (Fig. 1). The term British Empire Granite is proposed for the "S-type" intrusive body contained within the central section of the Mt Painter Block (Fig. 3), and the term Gordon Springs Granodiorite for the previously unmapped "I-type" intrusive found throughout the southern regions of the Mt Painter Block.

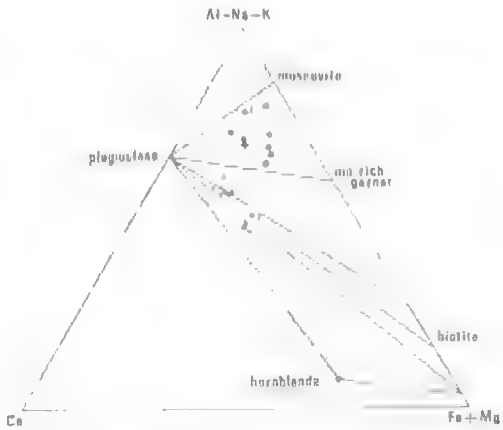

Fig. 6. Mt Painter Province Palaeozoic granitoids and associated minerals plotted in terms of Al-Na-K, Ca and Fe + Mg. Numbers (1-5) refer to granitoid compositions as shown in Table 1. (Symbols as for fig. 4.)

More complete isotopic and geochemical studies are being undertaken to determine more fully the age, petrogenesis and method of emplacement of these granitoids.

Acknowledgments

The author would like to thank Dr R. L. Oliver and Dr R. H. Flood for commenting on an earlier draft of this paper.

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STRATIGRAPHY OF THE EARLY CAMBRIAN EDEOWIE LIMESTONE MEMBER, FLINDERS RANGES, SOUTH AUSTRALIA

BY P. S. MOORE

Summary

The Edeowie Limestone Member comprises a thin unit of buff-coloured, flaggy weathering, dolomitic limestone. As previously defined in the literature, the member was assigned to the Lower to Middle Cambrian Billy Creek Formation. However, on both stratigraphic and sedimentological evidence, the sequence is considered to relate best to the limestones of the Hawker Group. The Edeowie Limestone Member is therefore reclassified as the uppermost member of the Orapinna Shale. The definition of the lower boundary of the Edeowie Limestone Member is also revised.

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Summary

MOORE, P. S. (1979)—Stratigraphy of the Early Cambrian Edeowie Limestone Member, Flinders Ranges, South Australia. *Trans. R. Soc. S. Aust.* **103**(4), 101-111, 31 May 1979.

The Edeowie Limestone Member comprises a thin unit of buff-coloured, flaggy weathering, dolomitic limestone. As previously defined in the literature, the member was assigned to the Lower to Middle Cambrian Billy Creek Formation. However, on both stratigraphic and sedimentological evidence, the sequence is considered to relate best to the limestones of the Hawker Group. The Edeowie Limestone Member is therefore reclassified as the uppermost member of the Oraparinna Shale. The definition of the lower boundary of the Edeowie Limestone Member is also revised.

Introduction

In their summary description of the Lower Cambrian stratigraphy of the western Flinders Ranges, Dalgarno & Johnson (1962) defined the base of the Billy Creek Formation as "a two foot thick fossliferous limestone which carries *Hyolithes*, unidentified brachiopods and occasional trilobite fragments". They continued: "This bed occurs ten feet or less below a prominent thin bedded and laminated dolomite which is an excellent marker throughout the area discussed". Between the fossiliferous limestone and the laminated dolomite there are greyish green silty shales. Thus, as previously defined, the Edeowie Limestone Member comprised the entire sequence from the base of the fossiliferous limestone to the top of the flaggy dolomite. In some areas, such as near the Bunyeroo Gorge and at Mernmerna, this definition meant that the lower half of the member comprised dominantly greyish green shale, identical in character to the underlying Oraparinna Shale. The present contribution redefines the base of the Edeowie Limestone Member so as to exclude this basal shale—carbonate sequence (Fig. 4), which is therefore included in the Oraparinna Shale, *sensu stricto*.

Although the Edeowie Limestone Member is represented in outcrops along the Heysen Range, at Mernmerna and in the southern part of the Wirrealpa Basin[1], it is absent from many other areas (Fig. 1). Thus, by including the Edeowie Limestone Member as part of the Billy Creek Formation, one may infer that the shales of the basal Billy Creek Formation are, in some areas, laterally equivalent to the Edeowie Limestone Member, or else that the base of the Billy Creek Formation is locally disconformable. Such a situation is considered by the author to be unlikely, for reasons discussed below. In addition, B. Daily (pers. comm. 1977) had originally included what was later termed the Edeowie Limestone Member in the type Oraparinna Shale.

Redefinition

Due mainly to the sporadic outcrop of the Cambrian sequence in the Flinders Ranges, the Edeowie Limestone Member cannot be traced unequivocally into its lateral stratigraphic equivalent. However, two outcrops, in the central and southern portions of the Wirrealpa Basin, support the author's view that the Edeowie Limestone Member passes laterally into other units of the Hawker Group.

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[1] The Wirrealpa Basin constitutes a tectonic basin formed during Delamerian folding, which occurs in the area adjacent to and south of the Wirrealpa homestead. The term was used by Mawson (1939), while describing the thick sequence of Cambrian strata which outcrop in the basin.

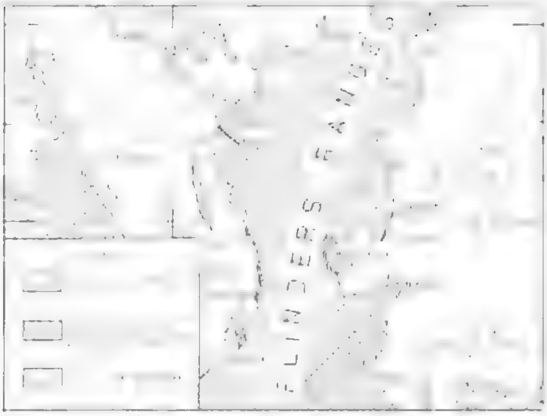


Fig. 1. Location map, showing outcrop of upper Lower to lower Middle Cambrian strata in the Flinders Ranges. The Edeowie Limestone Member occurs in the southern portion of the Wirrealpa Basin, at Mernmerna, and along the Heysen Range (Brachina/Bunyeroo) where it underlies redbeds of the Billy Creek Formation. It is absent however from several other outcrops (Mt Frome, Reaphook Hill, the northern and southern extremities of the Wirrealpa Basin, and the Mount Scott Range).

The Edeowie Limestone Member is shown by Dalgarno & Johnson (1966) as outcropping continuously along the Bunkers Range, from north of Balcoraeana Creek to south of Ten Mile Creek. In the most southern area of outcrop south of the Ten Mile Creek graben, the Edeowie Limestone Member is absent and redbeds of the Billy Creek Formation lie unconformably on Wilkawillina Limestone. Although outcrop is poor in the critical intervening area, it is apparent that the Edeowie Limestone Member does not thin to a featheredge and onlap the Wilkawillina Limestone on the southern flank of the graben, but instead, passes southwards with little thickness variation from evenly laminated limestone into evenly bedded dolomitic limestone. Interdigitated with the dolomitic limestone are two thin tongues of highly silicified, ?stromatolitic carbonate which can be traced laterally into the uppermost Wilkawillina Limestone. Thus, a transition appears to occur, from evenly laminated limestone into stromatolitic limestone on the southern margin of the Ten Mile Creek graben. This facies change is related to differences in water depth of the flank of the graben, with the highly silicified, ?stromatolitic carbonates deposited in relatively shallow water.

An identical situation occurs further north in the Wirrealpa Basin, where the Edeowie Limestone Member passes from an evenly laminated argillaceous limestone in the vicinity of Balcoraeana Creek into a highly silicified, ?stromatolitic limestone in its northernmost outcrop, approximately 1 km to the north. Unfortunately, the sequence in this area is complicated by faulting and poor outcrop, and the silicified limestones cannot be traced northwards along strike. Ten kilometres to the north however, near the Old Wirrealpa Mine, red and green shales of the Billy Creek Formation rest conformably on stromatolitic dolomite of the Wilkawillina Limestone. Since the Edeowie Limestone Member is present and well developed only 10 km to the south, the lateral transition with decreasing water depth from flaggy Edeowie limestone into stromatolitic Wilkawillina dolomite is considered in this case to be more likely than the alternate transition, from flaggy Edeowie limestone into shaly, non-calcareous redbeds of the Billy Creek Formation.

The Edeowie Limestone Member is also present along the Heysen Range, where it thickens towards the south in sympathy with other units of the Hawker Group. To the north in the Mount Scott Range, the Hawker Group is quite thin, and much of the sequence indicates deposition on a very shallow shelf. The Edeowie Limestone Member is absent, and non-calcareous redbeds of the Billy Creek Formation rest directly on stromatolitic dolomite of the Ajax Limestone. The contact has been excavated at a locality approximately 15 km northwest of the main road, and red shales of the Billy Creek Formation were observed draping perfectly preserved domal stromatolites of the Ajax Limestone. The lack of erosion of the stromatolitic domes indicates that the contact is a conformity or at most, an hiatus of insignificant duration. Thus, a transition from the flaggy Edeowie limestone in the centre of the basin, into stromatolitic dolomite of the basin margins is again considered to be the most likely sedimentological interpretation of the sequence. This view is supported by the fact that the stromatolitic dolomite and the flaggy Edeowie limestone are always mutually exclusive. Nowhere does the Edeowie Limestone Member rest on synsedimentary dolomites of the Hawker Group.

A small outcrop of Cambrian strata between the Heysen and Mount Scott Ranges provides some important information regarding lateral

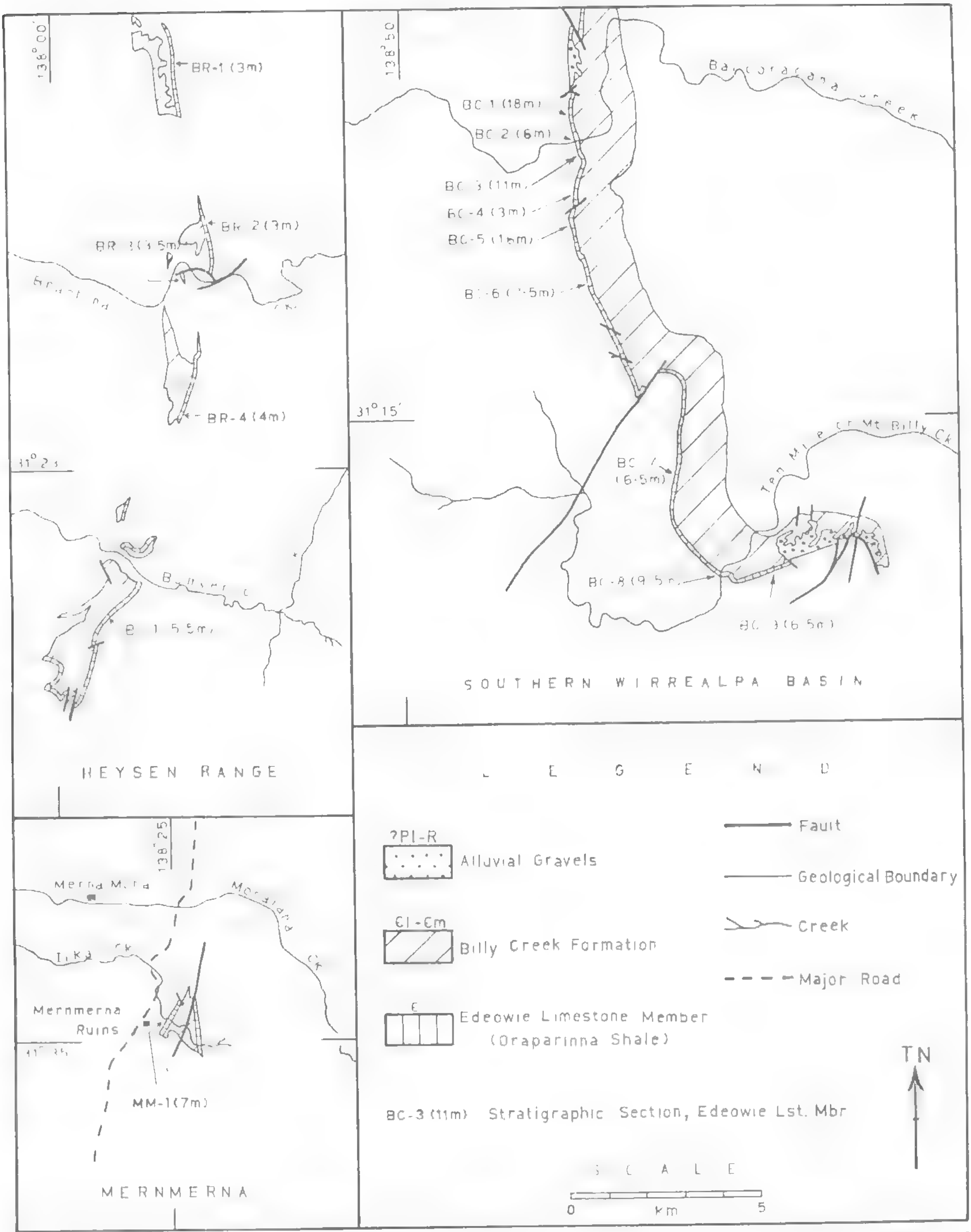


Fig. 2. Outcrop map of the Edeowie Limestone Member, showing positions and thicknesses of measured stratigraphic sections.

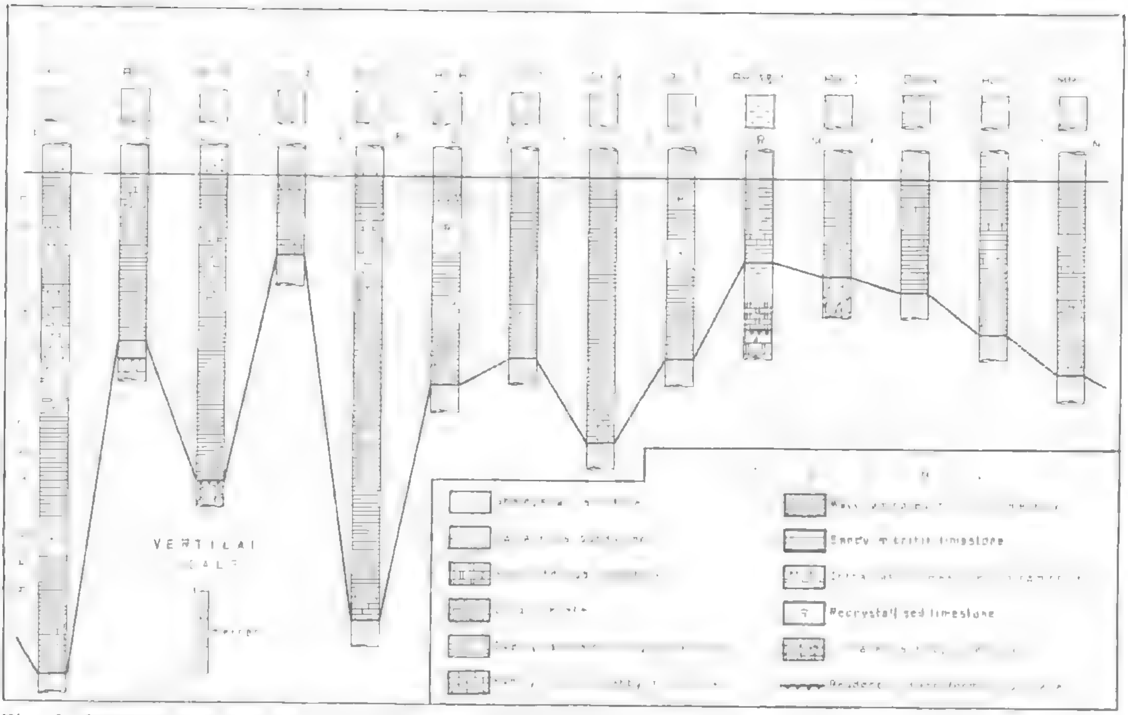


Fig. 3. Measured stratigraphic sections in the Edeowie Limestone Member.

facies changes in the uppermost Hawker Group. The outcrop is located approximately 12 km north of Parachilna, and is shown on the Parachilna 1:250 000 Geological Sheet (Dalgarno & Johnson 1966). The sequence at this locality is quite thin and the Oraparinna Shale, instead of being an olive green to black shaly siltstone, comprises a fine-grained sequence which is reddish in part, and contains several flaggy limestone intervals up to 2 m in thickness. These flaggy limestones are similar in character to outcrops of the Edeowie Limestone Member. This unusual variant of the Oraparinna Shale is inferred to pass northwards into the Ajax Limestone, and southwards into the more characteristic facies of the Oraparinna Shale.

In outcrops south of the Chambers Gorge, red and minor green shales and siltstones of the Billy Creek Formation rest conformably on the dominantly calcareous Moorowie Formation. The uppermost part of the Moorowie Formation (member II of Mount[2]) comprises grey, micritic limestone which becomes increasingly well bedded in stratigraphically higher units. The uppermost 6-9 m are dominated by platy to flaggy limestones similar in character to much of the Edeowie Limestone Member, although somewhat less dolomitic. Thus, the Edeowie Limestone Member is considered by the author to be the lateral equivalent of the uppermost part of the Moorowie Formation.

The Base of the Edeowie Limestone Member

In the vicinity of Ten Mile Creek in the Wirrealpa Basin, evenly laminated, flaggy, dolomitic limestone of the Edeowie Limestone Member rests conformably on a thick sequence of Oraparinna Shale (Figs. 5a, 5b). Further to the south, the Edeowie Limestone Member rests conformably on thinly bedded, rubbly Wilkawillina Limestone which intertongues with the Oraparinna Shale in the vicinity of a biohermal bank (Walter 1965[3], 1967). In the most southern outcrops in the Wirrealpa Basin, the Edeowie Limestone Member is absent and Wilkawillina Limestone containing Daily's

[2] Mount, T. D. (1970) Geology of the Mount Chambers Gorge region (B.Sc. (Hons) Thesis, University of Adelaide, unpublished).

[3] Walter, M. R. (1965) *Archaeocyatha* and the biostratigraphy of the Hawker Group near Wirrealpa, South Australia (B.Sc. (Hons) Thesis, University of Adelaide, unpublished).

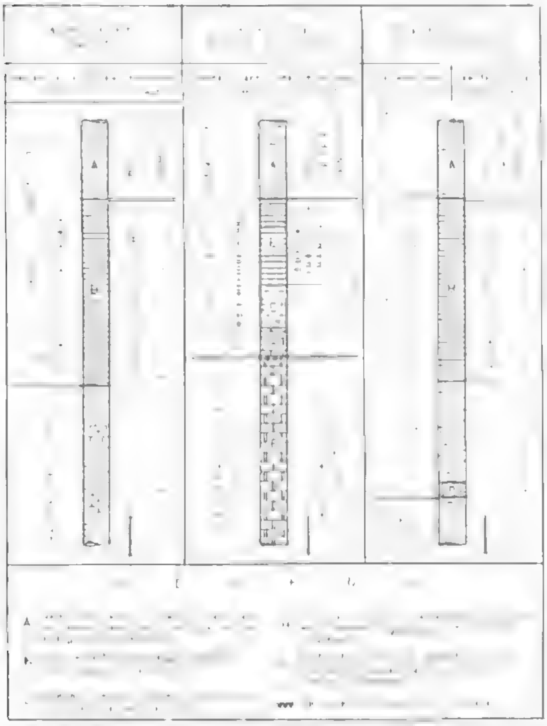


Fig. 4. Revised stratigraphic nomenclature for the Edeowie Limestone Member.

(1956) Faunal Assemblage No. 2 is either faulted against or overlain disconformably by redbeds of the Billy Creek Formation.

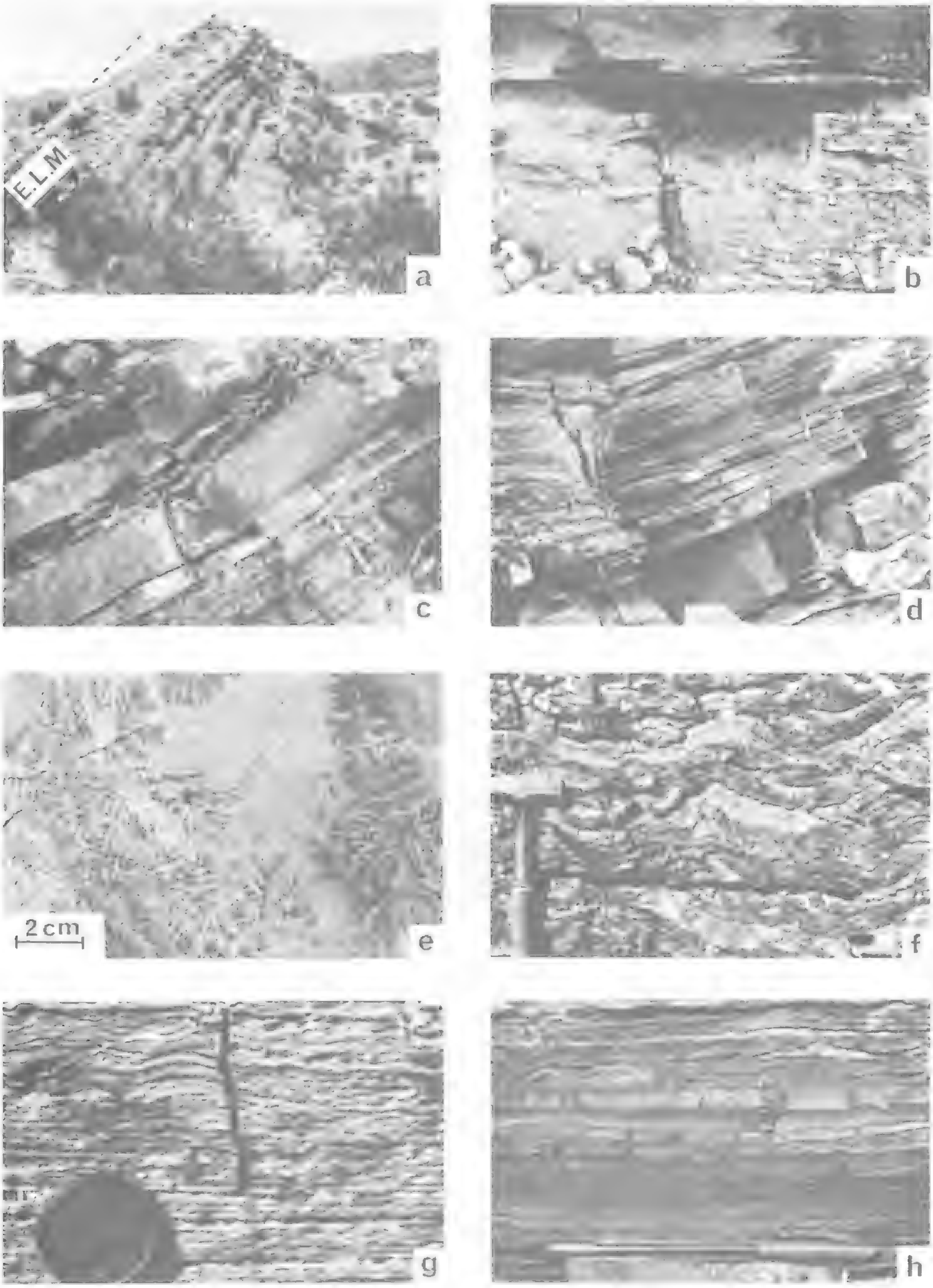
In the vicinity of Balcoracana Creek in the centre of the Wirrealpa Basin, the Lower Cambrian sequence is complicated by rapid lateral facies changes and disconformities related to tectonic instability (Fig. 6). In Balcoracana Creek and along its banks, richly fossiliferous Wilkawillina Limestone containing the Faunal Assemblage No. 2 is overlain disconformably by Oraparinna Shale. The upper surface of the Wilkawillina Limestone is very irregular and coated with a red, well laminated limestone, up to 5 cm in thickness. In addition, Daily (*in* Pierce[1]) identified sedimentary dykes emanating from the disconformity surface, in the upper portion of the Wilkawillina Limestone. The dykes comprise Parara Limestone and Bunkers Sandstone lithologies. The Edeowie Limestone Member rests conformably on approximately 2 m of green, silty Oraparinna Shale which overlies the disconformity surface. One exception occurs in the vicinity of Section BC–3 (Fig. 6), where the green shale lenses out and the Edeowie Limestone Member rests directly on the reddened disconformity surface. It appears that this very small area remained emergent during the deposition of the green Oraparinna shales, but finally was submerged during deposition of the Edeowie Limestone Member. This outcrop however is not of regional stratigraphic significance, since sedimentation and water depth in the vicinity of Balcoracana Creek were predominantly controlled by very local tectonic instabilities.

A short distance to the north and south of Balcoracana Creek, the sequence is more complete and both Parara Limestone and Bunkers Sandstone are present in normal stratigraphic sequence. The reddened surface can be resolved into two separate disconformities in this region (Fig. 6). The lower disconformity separates richly fossiliferous Wilkawillina Limestone containing Daily's (1956) Faunal Assemblage No. 2 from the overlying sequence. In the centre of the basins, dark grey, rubbly Parara Limestone is overlain by up to 10 m of conglomerate comprising clasts of Wilkawillina and Parara Limestone up to 1 m across. The upper surface of the conglomerate is reddened, and is overlain disconformably by Bunkers Sandstone. The Oraparinna Shale rests conformably on the Bunkers Sandstone and a well defined passage into the Edeowie Limestone Member is present.

Along the Heysen Range north of the Brachina Gorge, Wilkawillina Limestone containing the Faunal Assemblage No. 2 is disconformably overlain by a 1 m bed of medium grey, buff weathering calcareous siltstone with common *Hyolithes* and trilobite fragments, attributed in this paper to the Oraparinna Shale. The fossils are distributed randomly throughout the calcareous unit, and in many cases are relatively intact, indicating that the organisms underwent little transport after death. The disconformity surface is irregular, and is coated with red, well laminated limestone, up to 7 cm in thickness. The basal 1 m thick bed of calcareous siltstone to silty limestone is overlain by up to 1.5 m of dark grey, carbonaceous, silty shale which passes gradationally into flaggy, dolomitic limestones of the Edeowie Limestone Member (Fig. 4, middle column).

The sequence in the immediate vicinity of the Brachina Gorge has been described by

[1] Pierce, P. R. (1969) Cambrian geology south of the Wirrealpa Diapir, Flinders Ranges, South Australia. B.Sc. (Hons) Thesis, University of Adelaide (unpublished).


E.L.M.
a
b
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2 cm
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f
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h

Daily (1976) and is confirmed here. About 6 m of limestone conglomerate interbedded with silstone caps a reddened disconformity surface, developed on the richly fossiliferous Wilkawillina Limestone containing Daily's (1956) Faunal Assemblage No. 2. The conglomerate includes boulders of *Archaeocyatha* -rich limestone up to 2 m in diameter. The sequence is silty in the upper portion, and a passage into the Edeowie Limestone Member is indicated.

Along the Heysen Range south of Brachina Gorge, Edeowie Limestone Member is underlain by dark grey silty shales and siltstones of the Oraparinna Shale which contain *Redlichia* (B. Daily, pers. comm.). Thin limestone bands and lenses in the upper portion of the shaly unit indicate a passage into the overlying Edeowie Limestone Member. At the Bunyeroo Gorge and at Mernmerna, the underlying Oraparinna Shale is quite thick and comprises green, silty shale with minor, thin, fossiliferous carbonate beds. (Fig. 5c). A prominent, 30 cm thick, fossiliferous limestone unit, approximately 3.5 m below the base of the flaggy, dolomitic limestone, was taken by Dalgarno & Johnson (1962, 1963) as the base of the Edeowie Limestone Member (Fig. 4, right hand column). This classification is abandoned here and the fossiliferous limestone unit and overlying green and grey shales are excluded from the Edeowie Limestone Member and included within the underlying shaly member of the Oraparinna Shale.

The Top of the Edeowie Limestone Member

In most outcrops, the Edeowie Limestone Member is overlain conformably by red and green laminated shales of the Billy Creek Formation. The contact is poorly exposed as the flaggy limestone becomes platy and argillaceous, and passes upwards into greyish green shale. The passage zone is typically only 10–30 cm thick.

In the three small basins adjacent to Balcoracana Creek, the Edeowie Limestone Member is overlain conformably by a thin sesuence of pale brown, calcareous, medium-grained sandstones attributed to the basal Billy Creek Formation. The sandstones are cross-bedded to ripple-laminated, and pass laterally into red and green shaly siltstones more characteristic of the Billy Creek Formation.

Internal Stratigraphy

The Edeowie Limestone Member is dominantly a carbonate mudstone. The main lithologies are summarised below, and their regional distribution is given in Figure 3.

Evenly Laminated, Flaggy to Platy Limestone and Dolomitic Limestone

The greater proportion of the Edeowie Limestone Member comprises evenly laminated, flaggy to platy, carbonate mudstone which is in part dolomitic (Fig. 5d). Laminations are generally very even and continuous, and are defined by terrigenous mud laminae. Individual laminae may show graded bedding, from

Fig. 5. (a) Outcrop of the Edeowie Limestone Member at Daily's (1956) reference section, north of Ten Mile Creek. B. Daily (pers. comm. 1977) originally considered the flaggy Edeowie facies as part of the Oraparinna Shale at this locality. Note the abundance of dark calcareous bands in the underlying member of the Oraparinna Shale

(b) Sharp, conformable contact between greyish green Oraparinna shales and the Edeowie Limestone Member. Section BC-4, approx. 2 km south of Balcoracana Creek. Hammer height is 31 cm.

(c) Sharp, conformable contact between dark grey Oraparinna Shale and evenly bedded limestone of the Edeowie Limestone Member. Section BU-1, approx. 2 km south of the Bunyeroo Gorge.

(d) Flaggy, dolomitic limestone typical of the Edeowie Limestone Member. Section BC-4, approx. 2 km south of the Bunyeroo Gorge.

(e) Dendritic growth of pyrolusite on bedding planes of flaggy Edeowie Limestone Member. Section BC-1, approx. 1 km north of Balcoracana Creek.

(f) Siliceous nodules in recrystallized ?wavy Edeowie limestone, immediately south of Balcoracana Creek.

(g) Wavy laminated, micritic Edeowie Limestone Member. Section BC-6, approx. 5 km south of Balcoracana Creek. Lenscap diameter is 54 mm.

(h) Very thinly interbedded medium sandstone (light) and micritic limestone (dark). Shrinkage cracks in carbonate mudstone are infilled with sandstone. Section BC-5 in the Edeowie Limestone Member, approx. 3 km south of Balcoracana Creek. Pen diameter is 7 mm.

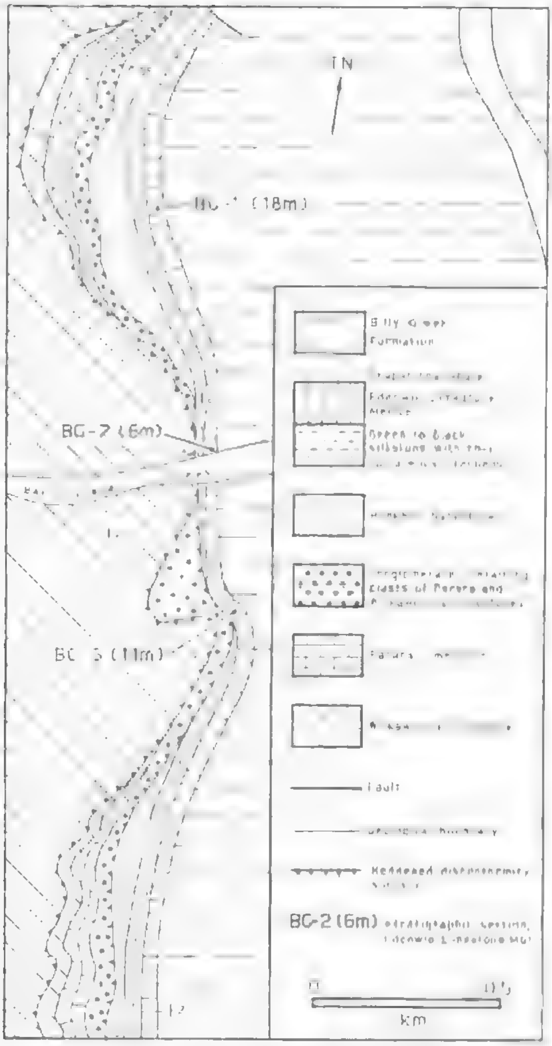

Fig. 6. Geological sketch map of Cambrian strata in vicinity of Balcoracana Creek.

microsparite (calcisiltite) to micrite (calcilutite). Terrigenous silt and fine to very fine sandstone are commonly asociated with the basal portions of graded laminae. The terrigenous content of this lithology is generally 3–8% and rarely exceeds 10%. Although dominated by subangular to subrounded quartz, a variety of mineral species is present, including a very mature suite of heavy minerals. A high terrigenous clay content is responsible for the yellowish brown colour of some intervals. Abundant dendritic pyrolusite is a common feature on bedding plane surfaces (Fig. 5e). Most samples are weakly dolomitic, and this feature is partly attributed to a high initial Mg/Ca ratio, associated with a restricted environment of deposition.

Wavy Laminated, Platy Limestone and Dolomitic Limestone

There is a complete gradation from the evenly laminated, carbonate mudstone described above, to this lithology which comprises light to medium grey, wavy laminated, platy, carbonate mudstone. The wavy laminations are most irregular and in some cases are discontinuous over a metre or less. Individual laminae are separated by very thin, ferruginous clay intervals. Terrigenous sand and silt grains may be concentrated along the boundary between successive carbonate laminae. Adjacent to Balcoracana Creek and south of the Ten Mile Creek in the Wirrealpa Basin, the limestone is strongly recrystallised and silicified (Fig. 5f).

The extreme fissility of this lithology is due to the concentration of terrigenous material into thin laminae. The wavy nature of the laminae is due in part to the extreme susceptibility of this fissile lithology to the effects of hillcreep and tectonic activity. However, in most cases the undulose laminations are attributed to sediment binding by algal mats (Fig. 5g). Domed stromatolites have not been observed in the Edeowie Limestone Member.

Intraclastic Limestone

In three small sedimentary basins adjacent to Balcoracana Creek, thick developments (up to about 20 m) of the Edeowie Limestone Member are present. Interbedded with the flaggy mudstone carbonates are units up to 0.6 m thick, comprising medium grey to pale grey, intraclastic limestone. This facies is typically poorly bedded and may be considerably sandy. Recrystallization to medium or coarse sparite is common in these units. The intraclasts are generally subrounded to rounded, micrite or sparite aggregates, up to 5 mm across. They form a packstone texture in which the interstices are filled with micrite or, less commonly, microsparite.

Thinly Interbedded Calcareous Sandstone and Sandy Limestone

This lithology is developed in the vicinity of Balcoracana Creek, particularly in the basal portions of the member. It comprises thin (0.5–3.0 cm) interbeds of sandy carbonate mudstone and calcareous, fine to medium sandstone (Fig. 5h). The sandy units generally consist of sub-rounded, quartz-rich, fine to medium sand with abundant, subrounded to rounded, micrite or microsparite intraclasts. Beds are evenly laminated to ripple laminated.

Graded bedding, from calcareous sandstone to sandy micrite is uncommon. In some cases, the sandy beds are loaded on the underlying carbonate mudstone. South of Balcoreacana Creek, small clastic dykes link sandy intervals. The sandstone dykes are contorted, due to post-injection compaction of the carbonate layers (Fig. 5h).

Tuffaceous, Silty Limestone

A thin, bright olive green tuffaceous unit up to 0.4 m thick has been identified from the Edeowie Limestone Member in several outcrops south of Balcoracana Creek. Its tuffaceous origin is principally interpreted from similar, less altered and coarser-grained lithologies in the overlying Billy Creek Formation. The tuffaceous unit comprises chloritic micrite and chloritic, silty mudstone. Quartz fragments are generally angular to subangular, and feldspar laths are grossly altered. The matrix comprises fine-grained, siliceous material, which has been extensively altered to chlorite and clay minerals. Altered, siliceous, angular fragments interpreted as devitrified shards are rare.

Interpretation of Facies

The absence of fossils in the Edeowie Limestone Member is probably related to the semi-restricted nature of the depositional environment. Flaggy limestones and dolomitic limestones (Fig. 5d) are interpreted as having accumulated on an intertidal to very shallow marine shelf during a period of regression. Argillaceous laminae indicate a very minor although persistent terrigenous influx. Wavy laminae (Fig. 5g) are considered to be of algal origin, although domal stromatolites have not been identified from the Edeowie Limestone Member. There remains the possibility however that the strongly silicified and recrystallised intervals (Fig. 5f) were originally stromatolitic.

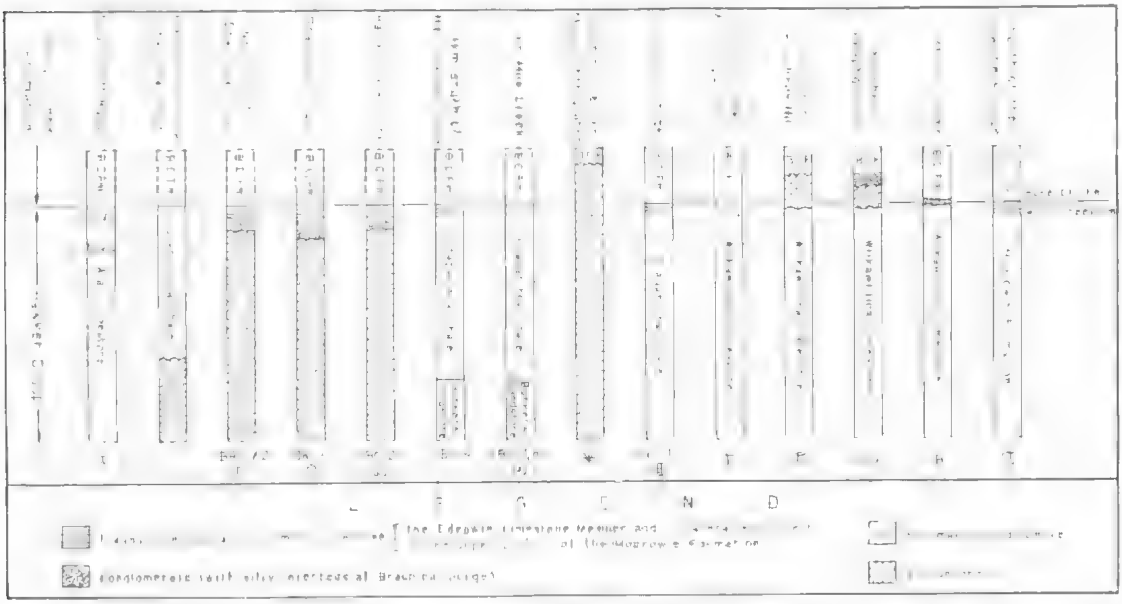

Fig. 7. Rock correlation chart for the uppermost portion of the Hawker Group (Lower Cambrian, Flinders Ranges). The stratigraphy of the various regions is discussed in general by: (A) Daily (1956); (B) Dalgarno (1964); (C) Daily (1976); (D) Pierce, P. R. (1969)[4]; (E) Gravestock, D. I. (1975) A study of *Archaeocyatha* (Class *Regulares* Vologdin, 1937) from the Wilkawillina Limestone near Wirrealpa Mine, Flinders Ranges, South Australia. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel); (F) Gaunt, G. F. M. (1971) The geology of the Kempes Bore area, eastern Flinders Ranges, South Australia. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel.); (G) Gehling, J. G. (1971) The geology of the Reaphook Hill area, Flinders Ranges, South Australia. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel.); (H) Wigglesworth, K. F. (1970) The geology of the Mount Frome region, Flinders Ranges, South Australia. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel.); (I) Mount, T. D. (1970)[2].

— Section may be complicated by faulting.

Terrigenous sandy and intraclastic limestones accumulated in response to more energetic conditions, in several small, relatively rapidly subsiding basins adjacent to Balcoracana Creek. Small clastic dykes in the very thinly interbedded sandstone—carbonate facies (Fig. 5a) appear to represent infilled shrinkage cracks. However, it is not known whether the shrinkage was caused by subaqueous or subaerial processes.

Regional Correlations

A rock correlation chart for the uppermost portion of the Hawker Group (late Early Cambrian, Flinders Ranges) is shown in Figure 7. Since the Edeowie Limestone Member appears to have accumulated in the central portions of the basin, it is to be expected that it occurs in a conformable sequence with other Cambrian units. Its association with the Oraparinna Shale is also consistent with deposition in the central basinal area, based on the simplified palaeogeographic reconstruction of the Hawker Group proposed by Wopfner (1969, Fig. 40). An exception occurs at Brachina Gorge (Fig. 7, fourth column from the left) where the Edeowie Limestone Member rests conformably on a sequence of conglomerates with silty interbeds. However, in the absence of palaeontological evidence, the conglomerates are assumed to be the lateral equivalent of green and grey siltstones of the Oraparinna Shale

Marginal areas where the Edeowie Limestone Member is absent include the outcrops along the Mount Scott Range and at Reaphook Hill. In the Mount Scott Range, the upper portion of the Ajax Limestone comprises a regressive sequence dominated in the upper portion by stromatolitic dolomite. The Billy Creek Formation rests conformably on the stromatolitic sequence, which is considered by the author to be the lateral equivalent of the Edeowie Limestone Member (Fig. 7, first column of the left).

A disconformity occurs at the base of the Billy Creek Formation at Reaphook Hill, and this outcrop may represent the eastern margin of the basin at the time of deposition of the Edeowie Limestone Member. In the southern portion of the Reaphook area, fenestral and oolitic Wilkawillina Limestone is overlain disconformably by marine sandstone of the Billy Creek Formation (Fig. 7, fourth column from the right). A thin (0.2–0.5 m) pisolitic calcrete caps the disconformity surface, indicating prolonged subaerial exposure. Further north, the disconformity surface is overlain by about 4 m of limestone conglomerate containing clasts of Wilkawillana Limestone eroded from adjacent areas (Fig. 7, third column from the right). The Edeowie Limestone Member is absent from the entire Reaphook Hill area and thus several interpretations of the sequence are possible. For example, the Edeowie Limestone Member in the Wirrealpa Basin may correlate with a period of non-deposition and subaerial exposure at Reaphook Hill. Alternatively, the Edeowie Limestone Member may have been deposited in the Reaphook area, but have been subsequently removed by erosion. This hypothesis is considered unlikely however, since there are no clasts of the Edeowie facies in the conglomerate at the base of the Billy Creek Formation. The interpretation favoured by the author is that the Edeowie Limestone Member was being deposited to the west while fenestral limestones presently assigned to the uppermost Wilkawillina Limestone accumulated in a marginal environment at Reaphook Hill.

Still further north at Mount Frome (Fig. 7, second column from the right), the Billy Creek Formation rests on dolomitized, sandy and in parts oolitic Wilkawillina Limestone which is interpreted to be the lateral equivalent of the Edeowie Limestone Member. A slight irregularity in the upper surface of the Wilkawillina Limestone is draped by shales of the Billy Creek Formation, suggesting that the contact may represent a minor disconformity or hiatus.

The area to the east of the Wirrealpa Diapir (Fig. 7, sixth column from the right) also appears to have been subject to very restricted and shallow water conditions during the deposition of the uppermost Hawker Group. As for the Mount Scott Range outcrops, the Edeowie Limestone Member is absent, and stromatolitic dolomite in the upper portion of the Wilkawillina Limestone is interpreted to be the lateral equivalent of the Edeowie facies. The shallow water nature of the sequence at this locality appears to be related to its proximity to the Wirrealpa Diapir, which was exposed and shedding detritus into the basin during the earlier stages of deposition of the Hawker Group.

Another area which was influenced by local tectonism was south of the Ten Mile Creek graben (Fig. 7, seventh column from the right). This block appears to have remained emergent during much of the late Early Cam-

brian. The lower one third of the Billy Creek Formation is absent, and the formation rests on dolomitized Wilkawillina Limestone which in the upper portion contains Daily's (1956) Faunal Assemblage No. 2. The Edeowie Limestone Member is absent, and was probably not deposited in the area due to the region's subaerial exposure at this period of time. Care must be taken in interpreting the outcrop however, since the Wilkawillina Limestone is strongly jointed and dissected by small faults. The contact between the Wilkawillina Limestone and Billy Creek Formation is not exposed, and a major fault along this boundary eliminating part of the sequence remains a distinct possibility.

Thus, the Edeowie Limestone Member represents the last major phase of Early Cambrian carbonate sedimentation in a contracting basin of deposition. It is overlain conformably by a markedly regressive sequence of redbed, tidal flat deposits of the Billy Creek Formation. On the basin margins, and in a few areas of relative tectonic stability within the basin, the Edeowie Limestone Member is absent and the Billy Creek Formation rests sharply and in some cases disconformably on stromatolitic and fenestral carbonates of the uppermost Hawker Group.

Conclusion

The Edeowie Limestone Member is redefined and reclassified as the uppermost member of the Oraparinna Shale and thus as part of the Lower Cambrian Hawker Group. It comprises medium grey to buff, flaggy, micritic limestone which is in part dolomitic. In the vicinity of Balcoracana Creek, thick developments of the Edeowie Limestone Member occur in three small basins which underwent greater relative subsidence in the Early Cambrian. In these regions, the limestone is slightly sandy and contains intervals of pale red, in part recrystallized and silicified, intraclastic limestone.

Acknowledgments

The author wishes to acknowledge discussion and helpful criticism by Dr B. Daily and Mr D. Gravestock of the University of Adelaide, and by Mr R. Dalgarno of the South Australian Department of Mines and Energy.

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VOL. 103, PARTS 5 & 6 31 AUGUST, 1979

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BY T. J. FATCHEN & S. BAKER

Summary

Local vegetation patterns in the Simpson Desert were objectively examined at seven sites near Lat. 26°S. The vegetation at most sites comprised a continuum of species, usually of regular cycle across dunes and related to soil stability. Variation in soil type was subordinate to soil in influence on vegetation.

CYCLIC VEGETATION PATTERN IN THE SOUTHERN SIMPSON DESERT

by T. J. FATCHEN* & SUSAN BARKER†

Summary

FATCHEN, T. J. & BARKER, S. (1979) Cyclic vegetation pattern in the southern Simpson Desert. *Trans. R. Soc. S. Aust.* **103**(5), 113-121, 31 August, 1979.

Local vegetation patterns in the Simpson Desert were objectively examined at seven sites near Lat. 26°S. The vegetation at most sites comprised a continuum of species, usually of regular cycle across dunes and related to soil stability. Variation in soil type was subordinate to soil stability in influence on vegetation.

Differences were found in the pattern of vegetation between sites due to variations in the species present, landform and, on Desert margins, domestic stock grazing. The effects of domestic stock grazing suggest that plant cover contributes more to the landscape's stability than is thought by some authors.

No regular vegetation pattern was found in the central Desert where dunes were less regular and less mobile than elsewhere. Also *Triodia basedowii* was absent, though normally regarded as typical of the Desert. These characteristics appear more significant in the southern Desert than is reported for the northern part, and represent the main landscape heterogeneity found during the study.

Introduction

The vegetation of the Simpson Desert has received scant attention since the initial study by Crocker (1946). Further detailed reports comprise only the single site studies of Boyland (1970) and Wiedemann (1971). The mapping of Perry *et al.* (1962), Specht (1972) and Laut *et al.* (1977) provides information in broad terms only, much of it derived from Crocker's report. Hence knowledge of the vegetation occupying 150 000 km² rests largely on one traverse and two studies on the margins.

Concern here is with small scale vegetation pattern. Local variation in the Desert is known to show a pattern concordant with that of soil stability; the mobile sands of the parallel dune crests carry a vegetation contrasting in structure and species composition to those of the more stable lower dune slopes and interdune corridors. This cyclic sequence is reported variously as an alternation of discrete Associations (Crocker 1946; Boyland 1970) or as continuous variation (Wiedemann 1971). Crocker lists several variants, of which the following are most significant. First, in an area "west of the Hay River", the dunes lose some of their regularity, becoming less mobile, and the vegetation pattern accordingly alters. Second, the presence of an *Acacia cambagei*-dominated Association is noted in restricted interdune corridors of the eastern Desert, additional to the usual *Zygochloa paradoxa* (dune crest) and *Triodia basedowii* (slope and corridor) Associations. Despite these variations, the impression remains of "a remarkable consistency" (Crocker 1946, p. 249).

The lack of interest in the vegetation indicated by the dearth of further studies may well stem from this impression. As well, the apparent physiographic uniformity of the area (Madigan 1938) may have led to an assumption of consequent uniformity in the vegetation.

A series of quantitative observations are reported here, taken from seven study sites distributed across the Desert near Lat. 26°S. and aimed at further examination of the nature of the vegetation and the variation in its pattern. The observations also extend sampling to a hitherto largely unreported area. This is the first report dealing in detail with the southern Simpson Desert, and the first in which quantitative information is provided from the Desert

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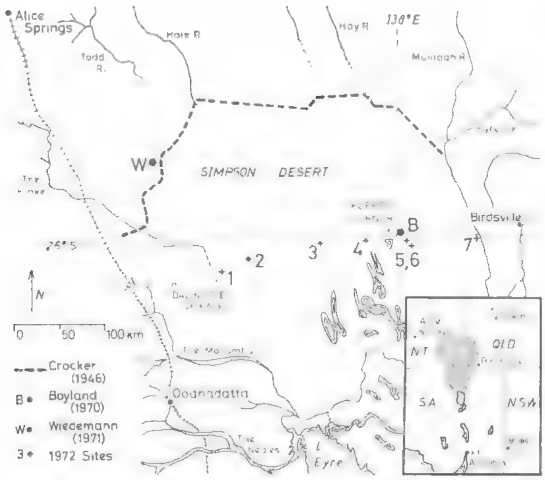

Fig. 1. Simpson Desert and surrounds showing 1972 study sites (numbers), Crocker's (1946) transect (dotted line) and the sites investigated by Boyland (1970) 'B' and Wiedemann (1971) 'W'.

interior. As such it provides a basis for a more accurate ecological assessment of this large but poorly investigated part of the continent.

Study site locations and descriptions

The Desert was traversed by vehicle from West to East in August 1972. A mining exploration track was followed from Dalhousie Springs, S.A., to Poeppel's Corner, and thence towards Birdsville, Qld, along Lat. 26°S (Fig. 1). In contrast to previous studies drought conditions prevailed before and during the crossing.

Observations were made at seven sites along this traverse (Fig. 1). Sites 1–3 had essentially the same physical characteristics: red regular dunes 10–15 m high, parallel and evenly spaced, unstable only at the crests and separated by sandy or occasionally sandy clay corridors. In the central Desert at site 4, dunes were yellow rather than red, lower than at the previous sites and irregular both in profile and trend, with stable rather than unstable crests. The area was homologous with the section of Crocker's (1946) traverse, already mentioned, west of the Hay River. Sites 5 and 6 were in yellow, regular dunes 15–30 m high, with unstable crests and predominantly clay interdunes, while site 7 was in similar dunes amongst the floodflats of the Mulligan River (Eyre Creek). Sites 1 and 7 were both grazed by domestic cattle, watering in the first case from Purni Bore (an uncapped artesian well sunk in 1961): and in the second from numerous waterholes in the Mulligan. Other sites were essentially ungrazed except by occasional small rabbit populations. Low open woodlands were found on interdune flats with sandy clay soils at sites 5 and 6 (*Acacia cambagei*) and at site 7 (*Eucalyptus microtheca*).

Methods

At all but site 6, a single belt transect of contiguous 4 m x 1 m quadrats was laid across the trend of the dunes, incorporating at least one complete topographic cycle. The incidences of all recognisable species encountered were scored, and the information processed by Influence Analysis (Lange 1968). Those unfamiliar with this technique should see also Barker & Lange (1969) and Lange (1971). Species were identified with reference to the checklist of Symon (1969).

At site 6, species' densities were sampled. The topographic profile was divided into four categories: dune crest (unstable sand), slipslope (steep eastern dune face, semi-stable sand), backslope (gentle western face, stable sand) and flat (interdune corridor, sandy clay loam overlying sandy clay). Three parallel transects, 400 m apart, were run across a profile comprising three crests, two backslopes and slipslopes, and one clay flat. Along the transects were laid 66 20 m x 1 m quadrats at regular intervals within categories, each at right angles to the transect. Slipslopes and crests were more intensively sampled relative to the ground area they represented, to approximate the sample sizes obtained on the other categories. All recognisable species were scored.

Results

Species' occurrences

Fifty-two species were found in quadrats (Table 1) from 87 species observed during the crossing (Appendix 1), but only nine species were common to all sites. These were the grasses *Aristida browniana, Enneapogon avenaceus, Eragrostis dielsii, Zygochloa paradoxa* and the herbaceous species *Atriplex limbata, Goodenia cycloptera, Salsola kali, Sida virgata* and *Tribulus hystrix*. Of these, *S. kali, E. avenaceus* and *A. browniana* were generally the most abundant, although usually individuals were dead. *Triodia basedowii*, supposedly the "most important plant in the Desert" (Crocker 1946), was absent from sites 4, 5 and 6, and present only at low frequencies at sites 3 and 7.

TABLE 1.
Relative frequencies of species' occurrences at study sites.

No.	*Species*	*Relative frequency (%) at sites**						
		1	*2*	*3*	*4*	*5*	*7*	*6*
	Group I: species showing significant positive association and found on stable soils.							
1	*Abutilon otocarpum*	29	30	—	—	26	10	—
2	*Aristida browniana*	22	83	62	43	80	57	+
3	*Atriplex limbata*	24	—	21	76	1	30	+
4	*Babbagia acroptera*	—	—	5	—	—	—	+
5	*Dissocarpus paradoxa*	—	—	19	—	—	—	—
6	*Sclerolaena wilsonii*	69	—	49	—	—	51	+
7	*Enneapogon avenaceus*	9	44	74	31	77	72	+
8	*Eremophila longifolia*	—	—	—	—	—	12	—
9	*Euphorbia wheeleri*	—	26	8	14	—	—	—
10	*Goodenia cycloptera*	60	37	15	55	3	18	+
11	*Leschenaultia divaricata*	4	5	1	2	—	—	—
12	*Phyllanthus fuernrohrii*	13	25	5	12	3	1	—
13	*Triodia basedowii*	41	56	8	—	—	3	—
	Group II: species showing significant positive association and found on unstable soils.							
14	*Enneapogon cylindricus*	—	16	—	2	—	—	—
15	*Eragrostis dielsii*	16	16	59	19	23	27	+
16	*Myriocephalus stuartii*	—	21	—	57	28	18	+
17	*Plagiosetum refractum*	—	28	35	55	16	18	+
18	*Ptilotus latifolius*	—	14	3	2	—	—	+
19	*Ptilotus polystachyus*	9	33	15	12	1	3	—
20	*Helichrysum ambiguum*	—	14	—	14	—	—	—
21	*Tribulus hystrix*	2	4	40	50	20	28	+
22	*Zygochloa paradoxa*	11	21	13	43	10	3	+
	Group III: species not displaying significant association; variable soil relationships.							
23	*Acacia cambagei*	—	—	—	—	—	—	+
24	*Acacia dictyophleba*	—	—	—	—	5	6	+
25	*Acacia ligulata*	—	7	—	7	5	—	—
26	*Acacia murrayana*	—	—	1	2	1	6	+
27	*Astrebla* sp.	—	—	11	—	—	—	—
28	*Atriplex inflata*	—	—	—	7	—	—	—
29	*Atriplex holocarpa*	—	—	1	—	—	—	—
30	*Atriplex vesicaria*	—	—	13	—	—	—	—
31	*Sclerolaena divaricata*	—	—	1	—	—	—	—
32	*Cassia nemophila* var *nemophila*	2	—	4	—	—	—	—
33	*Crotalaria cunninghamii*	—	—	—	—	—	—	+
34	*Crotalaria novae-hollandiae*	—	—	—	12	1	6	+
35	*Dactyloctenium radulans*	—	—	16	4	1	1	—
36	*Dicrastylis costelloi*	—	—	—	—	—	—	+
37	*Dodonaea attenuata*	—	3	—	—	38	—	+
38	*Eragrostis ?laniflora*	—	—	—	—	—	—	+
39	*Eremophila macdonnellii*	—	9	7	—	3	—	+
40	*Frankenia* sp.	—	—	—	—	—	—	+
41	*Maireana aphylla*	—	—	4	—	—	—	—
42	*Calotis erinacea*	—	30	—	—	—	1	+
43	*Portulaca oleracea*	—	—	—	—	—	—	+
44	*Ptilotus atriplicifolius*	9	17	1	14	—	—	—
45	*Rhagodia spinescens* var *deltophylla*	—	—	—	—	—	—	+
46	*Salsola kali*	80	65	48	86	69	25	+
47	*Scaevola depauperata*	11	5	—	4	—	—	—
48	*Sida corrugata*	13	28	9	6	—	—	—
49	*Sida virgata*	42	60	64	55	16	15	+
50	*Swainsona rigida*	—	—	—	—	—	—	+
51	*Tragus austalianus*	—	—	3	—	1	4	+
52	*Trichodesma zeylanicum*	—	—	11	17	11	3	+

* Presence only is indicated for site 6, as the sampling system used was not comparable with that at other sites.

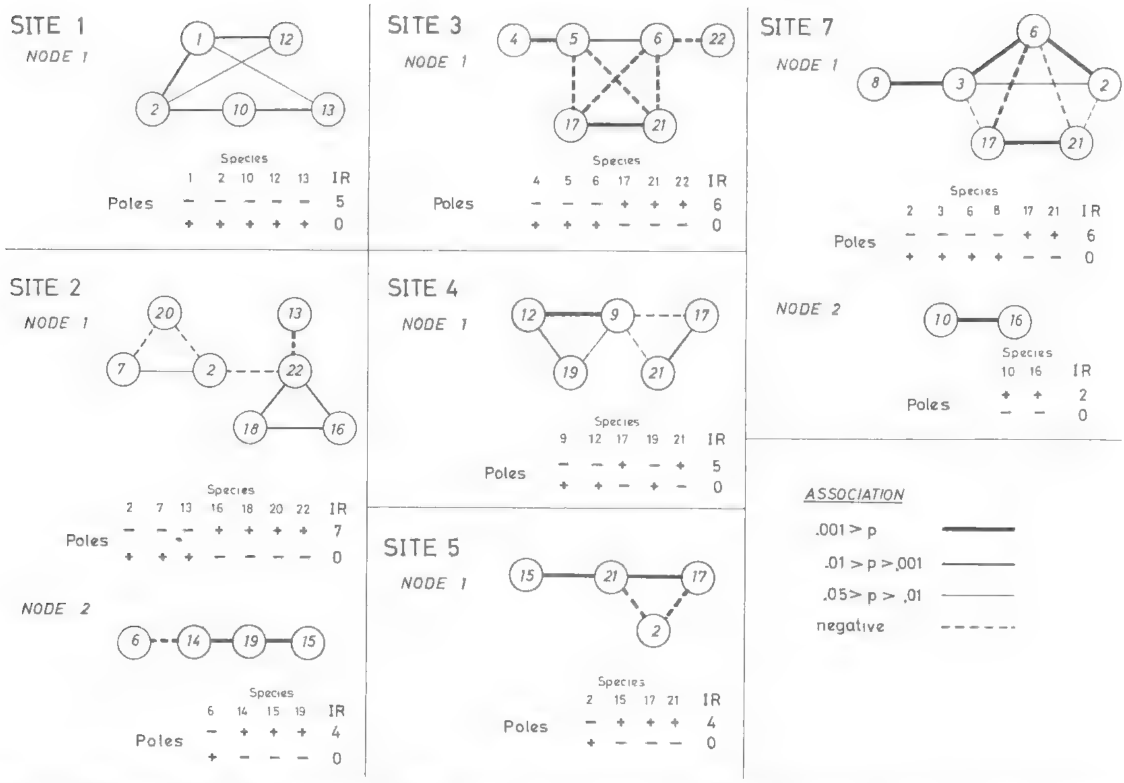

Fig. 2. Nodes of association, poles of interaction and assigned Influence Ratings (IR's) for each sample. Species numbers are those of Table 1.

Interdune corridors with sandy clay as the predominant soil type were sampled at sites 2, 3, 5, 6 and 7, but did not noticeably alter the array of species encountered except at the site 3. Here, a low open shrubland of *Atriplex vesicaria* was found in one corridor with the only occurrences in quadrats of the chenopods *A. vesicaria, A. holocarpa, Sclerolaena divaricata, Dissocarpus paradoxa, Maireana aphylla* and the Mitchell Grass *Astrebla* sp. Low open woodlands on clay flats at sites 5 and 6 (*Acacia cambagei*) and site 7 (*Eucalyptus microtheca*) certainly altered the appearance of the vegetation but had little influence on the understorey species list. Trees at these latter sites were well spaced—at site 6, *A. cambagei* occurred in four of 14 quadrats laid in the woodland, but no trees were found in quadrats at other sites.

Influence Analyses of vegetation pattern

The nodes of species association and the assignment of Influence Ratings (IR's) are shown in Fig. 2. Small quadrat size and low replication limited the degree of reinforcing within nodes—statistical associations tended to appear as chains rather than webs of associated species—but the outline of associations is clear. Twenty-two species contributed to the nodes detected, although not all at any one site. Enough combinations exist, however, to indicate the pattern of association most likely to arise if all species were to be present simultaneously. Given this, the species of Table 2 are divided into three groups, the first two having within-group positive association but with negative association between groups. Group III represents species which because of their low abundance or ubiquitous distributions showed no significant association.

On the basis of their constituent species, groups I and II conform respectively to the *Triodia basedowii* and *Zygochloa paradoxa* Associations of Crocker (1946), the former associated with the stable soils of slopes and corridors, and the latter with the unstable sand of dune crests.

In Fig. 3, Influence Ratings (IR's) are backplotted against distance for the individual nodes at each site. For consistency in presentation, IR's have been assigned so that a high

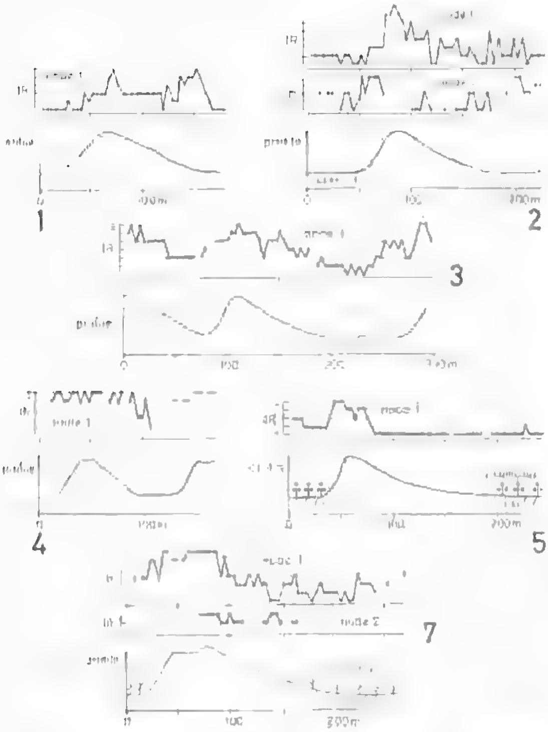

Fig. 3. Influence Ratings backplotted against length of transect for 6 sites in the Simpson Desert. Breaks in the plots indicate quadrats with no score. The accompanying topographic profiles are diagrammatic only and are laterally distorted (see text).

IR indicates that expression of the influence favouring group II species. Points on the plot are evenly spaced for clarity: since the quadrats followed the ground contour, the accompanying sketches of the transect profile are distorted accordingly.

In areas of regular, ungrazed dunes (sites 2, 3 and 5), the major influence of soil stability is clearly shown by the backplots of the first node at each site. A pronounced cyclic vegetation exists parallel to the topographic cycle and so to soil stability. Crests and upper dune slopes display the highest IR's, with lower values for the lower slopes and interdunes. A further node is found at site 2, apparently indicating a secondary influence associated with the base of the slipslope.

The backplot for node 1 at site 7 also shows the influence of soil stability in the same manner, while a second node indicates an undetermined influence associated with upper dune slopes. There is no evidence in the analysis of any perturbations which might be ascribed to domestic grazing, although the frequencies at which species occurred were generally lower here than elsewhere (Table 1).

At site 1, the transect ran across one dune into the corridor containing Purni bore and its drain, on which cattle were concentrated. As in the previous cases, IR's increase to a maximum on the mobile dune crest, then decrease along the backslope; but where the dune merges into the corridor, near the bore drain, IR's again increase to a level as high as that found on the crest. The influence displayed must be soil stability, given the pattern of the first half of the transect, hence the rest of the plot indicates that the corridor-dune junction has become as unstable as the crest.

Compared with other sites, the vegetation was relatively uniform in the irregular dunes at site 4. Overall high IR's along the transect suggest a high degree of instability, but while

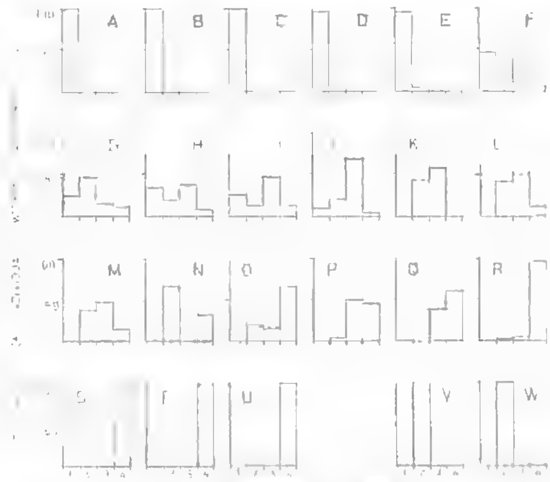

Fig. 4. Proportional distribution of individuals for each species on topographic categories at site 6, corrected for equivalent sample size in each category. Categories: 1, clay flat, stable soils; 2, backslope, stable sand; 3, slipslope, semi-stable sand; 4, dune crest, mobile sand. Species: A, *Acacia cambagei*; B, *Tragus australianus*; C, *Dicrastylis costelloi*; D, *Sclerolaena wilsonii*; E, *Atriplex limbata*; F, *Aristida browniana*; G, *Sida virgata*; H, *Enneapogon avenaceus*; I, *Salsola kali*; J, *Portulaca oleracea*; K, *Acacia murrayana*; L, *A. dictyophleba*; M, *Trichodesma zeylanicum*; N, *Swainsona rigida*; O, *Goodenia cycloptera*; P, *Tribulus hystrix*; Q, *Plagiosetum refractum*; R, *Crotalaria cunninghamii*; S, *C. novae-hollandiae*; T, *Ptilotus latifolius*; U, *Zygochloa paradoxa*; V, *Calotis erinacea*; W, *Dodonaea attenuata*. For densities refer Appendix 2.

evidence at the site indicated recent deflation (e.g. wind-cut plinths around the bases of perennial bushes) the dunes appeared to be much more stable than at the other sites, with very little mobile sand present.

Density distributions

Only seven species at site 6 were restricted entirely to a particular topographic category: *Acacia cambagei, Tragus australianus* and *Dicrastylis costelloi* on clay flats, *Calotis erinacea* and *Dodonaea attenuata* on backslopes, and *Crotalaria novae-hollandiae, Ptilotus latifolius* and *Zygochloa paradoxa* on mobile dune crests. Although other species showed a preference for a particular category, considerable overlap occurred. A continuous gradient in species' incidence and abundance relative to the categories is in fact displayed by Fig. 4, in which the species restricted to flats and crests respectively represent the two extremes of the gradient. (*C. erinacea* and *D. attenuata* do not appear to fit in the sequence, but this may result from minimal abundances—see Appendix 2.)

Essentially, the findings replicate the results of analyses already given. Most species distributions relate to the primary influence of soil stability in the manner expected from the Influence Analyses. Two exceptions are *Eragrostis dielsii* and *Goodenia cycloptera* which at this site show a preference for stable and unstable soils respectively.

Discussion

The nature of the communities

The continuous variation highlighted by analyses supports Wiedemann's (1971) contention of a vegetation continuum along the dune-interdune cycle rather than a separation into more-or-less distinct associations as proposed by Crocker (1946) and Boyland (1970). The continuum relates directly to soil stability, the major and often only influence detected. Further, the type of substrate appears to have little effect on the expression of this continuum. Clay-dominated soils in interdune corridors at sites 2. 3, 5 and 7 introduced no perturbations to plots of the influence, and only at site 3 was the array of species present significantly altered by the increased soil diversity. Species restricted to clay soils at site 6 appear to represent more an extreme of a sequence encompassing both sand and clay soils than a group in their own right. Thus even the *Acacia cambagei* woodlands at sites 5 and 6 could be considered as part of the one continuum rather than a distinct Association, despite the major and obvious differences in substrate and appearance. Separate classification and mapping, not only of dune Associations but also of these woodlands, may be convenient for rapid and subjective appraisal but misleading in terms of the system's operation: the trees catch the eye but are unlikely to be exerting much influence on the rest of the vegetation because of their wide spacing (see also Wiedemann 1971).

Wiedemann (1971), as well as demonstrating the existence of the above continuum at his study area, also defined a number of "habitat types". Some support for this curiously ambivalent reclassifying of the vegetation might be seen in the present study, in that the influences expressed by node 2 at site 2 and node 2 at site 7 may correspond to his "lower slope clayey sand" and "mid-slope clayey sand" habitats. However, the results given here show that these variations are minor indeed by comparison with the over-riding influence of soil stability.

Variation in vegetation pattern between sites

The cyclic pattern in the vegetation is clearly not consistent across the Desert. Three sources of variation are found; in the species present at any one site, in landform, and in the impact of domestic stock. Much of the first source may stem from differences in the levels of sampling replication or in time since last plant growth, but differences due to varying distributions on a biogeographic scale were also noted. Although a discussion of the last is beyond the scope of this paper, the absence of *Triodia basedowii* from the central Desert sites warrants mention in view of the reported importance of the plant. In the western Desert, *T. basedowii* is the most frequently encountered perennial, and Crocker (1946) and Wiedemann (1971) indicate its significance as an influence on other species present. Hence changes in the distribution of associated species would be expected to accompany its disappearance.

The absence of a clearly defined vegetation pattern at site 4 reflects differences in landform between this and other parts of the Desert: differences which are not confined to the southern Desert but apparently extend to the latitude of Crocker's crossing. The results are confusing: the site showed at the same time evidence of recent deflation and an absence of mobile sand, while analysis of the

vegetation suggests that it was more unstable, area for area, than any of the other sites. The peculiarities of this part of the Simpson dune system require further investigation.

Domestic grazing on the Desert fringes has had a decided impact. Wiedemann (1971) suggested that the landscape's stability was relatively unaffected by the level of plant cover, but the effects of cattle grazing at Purni Bore suggest otherwise. Stock movement and feeding on the lower dune slopes at site 1 have increased sand mobility to a level equivalent to that of the dune crests. Certainly this is a case, albeit local, where the removal of vegetation has led to greater instability. Additionally, the sand-binding value even of dead plants is often under-estimated. At site 5, ephemeral species (particularly *Salsola kali*) were so long dead as to have turned black, yet were still binding the lower slopes of the dunes (see also Crocker 1946). Nearer Birdsville, dunes have deflated and shifted following grazing, as shown by *Acacia cambagei* trees of the flats in process of burial. The impression still remains one of fragility, with the plant cover a major factor in dune stabilisation.

The lesser impact of stock at site 7 probably results from a greater dispersion of animals. At this site, changes in vegetation patterns due to stock were not detected, but an overall reduction in frequencies of occurrence was noted, relative to other sites.

Comparison with Crocker's (1946) descriptions

In general terms, the local vegetations at the latitude of the 1972 crossing are much the same as those described by Crocker (1946) for a lower latitude. Differences stem more from the approaches and emphases of observers than from the vegetation itself. However, the irregular dune system represented by site 4 would appear to be in greater contrast with the rest of the Desert than Crocker indicated; while the *Acacia cambagei* woodlands, noted on "restricted" corridors in the eastern Desert by Crocker, appear to be a more widespread component of the vegetation in the southern Desert. The latter has been noted also by Boyland (1970). These reservations apart, observations at intermediate latitudes can be expected to return equivalent results.

Acknowledgments

We wish to thank C. R. Harris and Rob Marshall who organised and led the party; the Department of Geography, University of Adelaide, the Research School of Biological Sciences, Australian National University, the South Australian Department of Agriculture and members of the party for vehicular and financial support; and D. H. Fatchen for the line drawings. Mr D. E. Symon kindly checked nomenclature in the plant lists. At the time of the study, T.J.F. was recipient of a Commonwealth Postgraduate Research Award in the Department of Botany, University of Adelaide, while S.B. was a postdoctoral Fellow in the Research School of Biological Sciences, Australian National University.

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APPENDIX 1

PLANT SPECIES OBSERVED IN THE SOUTHERN SIMPSON DESERT AT LAT. 26 S

* Indicates flowering material verified by the State Herbarium of South Australia.

TYPHACEAE

**Typha domingensis* Pers

GRAMINAE (POACEAE)

**Aristida browniana* Henr.
A. contorta F. Muell.
Enneapogon avenaceus (Lindl.) C. E. Hubbard
E. cylindricus N. T. Burb.
Eragrostis dielsii Pilger
E.? laniflora Benth.
**Plagiosetum refractum* (F. Muell.) Benth.
Tragus australianus S. T. Blake
Triodia basedowii E. Pritzel
**Zygochloa paradoxa* (R. Br.) S. T. Blake

CYPERACEAE

**Cyperus laevigatus* L.
**C. gymnocaulos* Steud.

PROTEACEAE

Grevillea juncfolia Hook.
**Hakea divaricata* Johnson
H. leucoptera R. Br.

SANTALACEAE

Santalum lanceolatum var. *angustofolium* R. Br.

CHENOPODIACEAE

Atriplex inflata F. Muell.
**A. limbata* Benth.
A. nummularia Lindl.
A. holocarpa F. Muell.
A. vesicaria Heward ex Benth.
Babbagia acroptera F. Muell. & Tate
**Dissocarpus paradoxa* (R. Br.) F. Muell. ex Ullrich
Maireana aphylla (R. Br.) P. G. Wilson
M. astrotricha (L. A. S. Johnson) P. G. Wilson
M. pyramidata (Benth.) P. G. Wilson
Rhagodia spinescens var. *deltophylla* (F. Muell.) Black
**Sclerolaena andersonii* (Ising) Scott
**S. bicornis* Lindl.
S. divaricata (R. Br.) Domin
S. muricata (Moq.) Domin
**S. wilsonii* (Ising) Scott
**Salsola kali* L.

AMARANTHACEAE

Ptilotus atriplicifolius (Cunn. ex Moq.) Benth.
**P. latifolius* R. Br.
**P. obovatus* (Gaudich) F. Muell.
**P. polystachyus* (Gaudich) F. Muell.

AIZOACEAE

Aizoon quadrifidum (F. Muell.) F. Muell.
**Trianthema pilosa* F. Muell.

PORTULACACEAE

Portulaca oleracea L.

MIMOSOIDEAE

**Acacia cambagei* Baker
**A. dictyophleba* F. Muell.
**A. ligulata* Cunn. ex Benth.
A. linophylla Fitz.
**A. murrayana* F. Muell. ex Benth.
A. oswaldii F. Muell.
A. tetragonophylla F. Muell.
A. victoriae Benth.

CAESALPINIOIDEAE

Bauhinia carronii F. Muell.
**Cassia nemophila* var. *nemophila* (Cunn. ex Vogel) Symon
C. nemophila var. *zygophylla* (Benth.) Symon

PAPILIONATAE

**Crotalaria cunninghamii* R. Br.
**C. novae-hollandiae* DC.
**Psoralea eriantha* Benth.
Swainsona rigida (Benth.) Black

ZYGOPHYLLACEAE

Nitraria billardieri DC.
Tribulus hystrix R. Br.
**Zygophyllum billardieri* DC.

EUPHORBIACEAE

Euphorbia drummondii Boiss
**E. wheeleri* Baill.
**Phyllanthus fuernrohrii* F. Muell.

SAPINDACEAE

Atalaya hemiglauca (F. Muell.) F. Muell. ex Benth.
Dodonaea attenuata Cunn.

MALVACEAE

**Abutilon otocarpum* F. Muell.
Sida corrugata Lindl.
S. virgata Hook.

UMBELLIFERAE (APIACEAE)

**Trachymene glaucifolia* (F. Muell.) Benth.

THYMELEACEAE

**Pimelea ammocharis* F. Muell.

MYRTACEAE

Eucalyptus microtheca F. Muell.

BORAGINACEAE

Trichodesma zeylanicum (Burm. f.) R. Br.

CHLOANTHACEAE

**Dicrastylis costelloi* Bailey

MYOPORACEAE

**Eremophila longifolia* (R. Br.)
**E. macdonnellii* F. Muell.
**E. willsii* F. Muell.

GOODENIACEAE

**Goodenia cycloptera* R. Br.
**Leschenaultia divaricata* F. Muell.
**Scaevola collaris* F. Muell.
**S. depauperata* R. Br.

COMPOSITAE (AESTERACEAE)

**Calotis erinacea* Steetz
**Calocephalus knappi* (F. Muell.) Ewart et White
**Helipterum floribundum* DC.
**Helichrysum ambiguum* Turoz.
**Myriocephalus stuartii* (F. Muell. and Sond ex Sond) Benth.
**Senecio gregorii* F. Muell.

APPENDIX 2
DENSITY DATA FROM SITE 6

Mean densities with associated standard errors for species on each of the topographic categories at site 6. The order of species is as in Fig. 4. Values are in plants per 10 m^2.

Category:	*Flat*	*Backslope*	*Slipslope*	*Crest*
Sample size:	*14*	*22*	*12*	*18*
Species				
Acacia cambagei	0.2 *	—	—	—
Tragus australianus	0.4 ± 0.70			
Dicrastylis costelloi	0.1 *	—	—	—
Sclerolaena wilsonii	8.1 ± 2.07	0.1 *	—	—
Atriplex limbata	1.8 ± 1.44	0.1 *	—	—
Aristida browniana	48.5 ±12.67	41.4 ± 2.58	10.0 ± 4.95	3.3 ± 0.87
Sida virgata	1.5 ± 0.89	2.9 ± 1.00	0.9 ± 0.47	0.8 ± 0.27
Enneapogon avenaceus	9.1 ± 1.79	4.9 ± 1.03	9.7 ± 2.13	2.3 ± 0.87
Salsola kali	10.2 ± 2.15	5.0 ± 0.80	17.7 ± 6.10	4.9 ± 1.83
Portulaca oleracea	3.1 ± 1.56	5.7 ± 3.44	19.0 ± 3.75	0.2 ± 0.17
Acacia murrayana	—	0.2 ± 0.07	0.2 *	—
Acacia dictyophleba	—	0.3 ± 0.13	0.4 ± 0.11	0.1 *
Trichodesma zeylanicum	—	11.0 ± 2.24	13.6 ± 2.57	3.8 ± 1.46
Swainsona rigida	—	0.7 ± 0.31	—	0.4 ± 0.30
Goodenia cycloptera	—	1.3 ± 0.60	0.8 ± 0.55	4.0 ± 1.43
Tribulus hystrix	—	0.1 *	1.7 ± 0.80	1.5 ± 0.48
Plagiosetum refractum	—	0.1 *	2.0 ± 0.90	3.1 ± 0.97
Crotalaria cunninghamii	—	0.1 *	0.1 *	1.9 ± 1.88
Crotalaria novae-hollandiae	—	—	—	0.5 ± 0.18
Ptilotus latifolius	—	—	—	0.4 ± 0.28
Zygochloa paradoxa	—		—	2.0 ± 0.45
Calotis erinacea	—	—	0.1 *	—
Dodonacea attenuata	—	—	0.2 ± 0.08	—
Babbagia acroptera	a	—	—	—
Eragrostis ?laniflora	a	—	—	—
Frankenia sp.	a	—	—	—
Myriocephalus stuartii	b	b	b	b

* denotes less than 5 occurrences, 'a' a single occurrence and 'b' fragments.

ALOCOSTMA NEW GENUS (NEMATODA: TRICHONEMATIDAE)

BY PATRICIA M. MAWSON

Summary

Alcostoma is related to the genera Macropostrongylus and Macroponema. It is distinguished by the presence of longitudinal striae in the anterior part of the lining of the buccal cavity, and by the very distinctive cylindrical submedian cephalic papillae. A diagnosis is given of the new genus, as well as a partial redescription of the type species, Cyclostrongylus clelandi.

ALOCOSTOMA NEW GENUS (NEMATODA: TRICHONEMATIDAE)

by PATRICIA M. MAWSON*

Summary

MAWSON, P. M. (1979) *Alocostoma* new genus (Nematoda: Trichonematidae). *Trans. R. Soc. S. Aust.* **103**(5), 123-126, 31 August, 1979.

Alocostoma is related to the genera *Macropostrongylus* and *Macroponema*. It is distinguished by the presence of longitudinal striae in the anterior part of the lining of the buccal cavity, and by the very distinctive cylindrical submedian cephalic papillae. A diagnosis is given of the new genus, as well as a partial redescription of the type species, *Cyclostrongylus clelandi*.

Introduction

Cyclostrongylus Johnston & Mawson was revised by Mawson (1977), *C. clelandi* being noted as belonging to an undescribed genus. This species is now redescribed, and proposed as the type of a new genus *Alocostoma*. New material is now available; though not numerous in any one host animal, specimens have been taken over a wide geographical range and from two host species.

Alocostoma gen. nov.

Trichonematidae: Small worms; anterior end with well developed cuticular collar, submedian cephalic papillae cylindrical, truncated; circumoral cuticle and lining of anterior buccal cavity finely striated; buccal capsule lightly chitinised, its shape mobile; oesophagus long and slender, with terminal bulb. Male: bursa not joined ventrally; ventral rays together, ventro-lateral rays divergent from other laterals, externo-dorsal rays arise with laterals, divergent from them; dorsal ray bifurcates, each branch giving off lateral stem; spicules alate, gubernaculum present. Female: tail conical, vulva close to anus, ovijectors opposed, parallel to body length. Parasitic in macropodid marsupials.

Type species: *Cyclostrongylus clelandi* Johnston & Mawson.

Alocostoma most closely resembles *Macropostrongylus* Yorke & Maplestone, 1926 and *Macroponema* Mawson, 1978 which have a long oesophagus with a terminal bulb, the buccal capsule not strongly chitinised, and lips and leaf crown absent. It differs in the shape of the buccal capsule and of the cephalic papillae.

Alocostoma clelandi (Johnston & Mawson)

FIGS 1–11

Cyclostrongylus clelandi Johnston & Mawson, 1939b, from *Macropus major*. Coonamble, N.S.W.

Hosts and localities: *Macropus giganteus* Shaw: Brisbane Ranges (1 ♂), Yan Yean (5 ♀), Fraser Ntl Park (2 ♂), Bendigo (1 ♂, 1 ♀), Victoria; St George, Qld 1 ♀); N.S.W. (1 ♂). *Macropus robustus* Gould: Rivertree, N.S.W. (9 ♂, 9 ♀); Kimberley region, W.A. (4 ♂, 12 ♀).

The original description of this species can now be amplified, especially in regard to the anterior end.

Wide, thick cuticular collar around anterior end pierced around its periphery by cephalic papillae and amphids. Cephalic papillae of distinctive shape: cylindrical, abruptly truncated distally, and with small depression in centre of free end. Area around mouth finely striated radially, and striae continue into anterior part of buccal cavity as well marked longitudinal lines. Labial collar can be raised as narrow frill around mouth or depressed below level of outer cephalic collar, not comparable with leaf crown as it appears in *Cloacina* spp. and *Murshida* spp., but similar to labial fringe present in *Papillostrongylus labiatus* Johnston & Mawson (1939a) and labial flange in *Macroponema* spp. (Mawson 1978). Shape of mouth varies—round, elongate, or pursed (Fig. 4).

More or less cylindrical buccal capsule so lightly chitinised as to be almost invisible in

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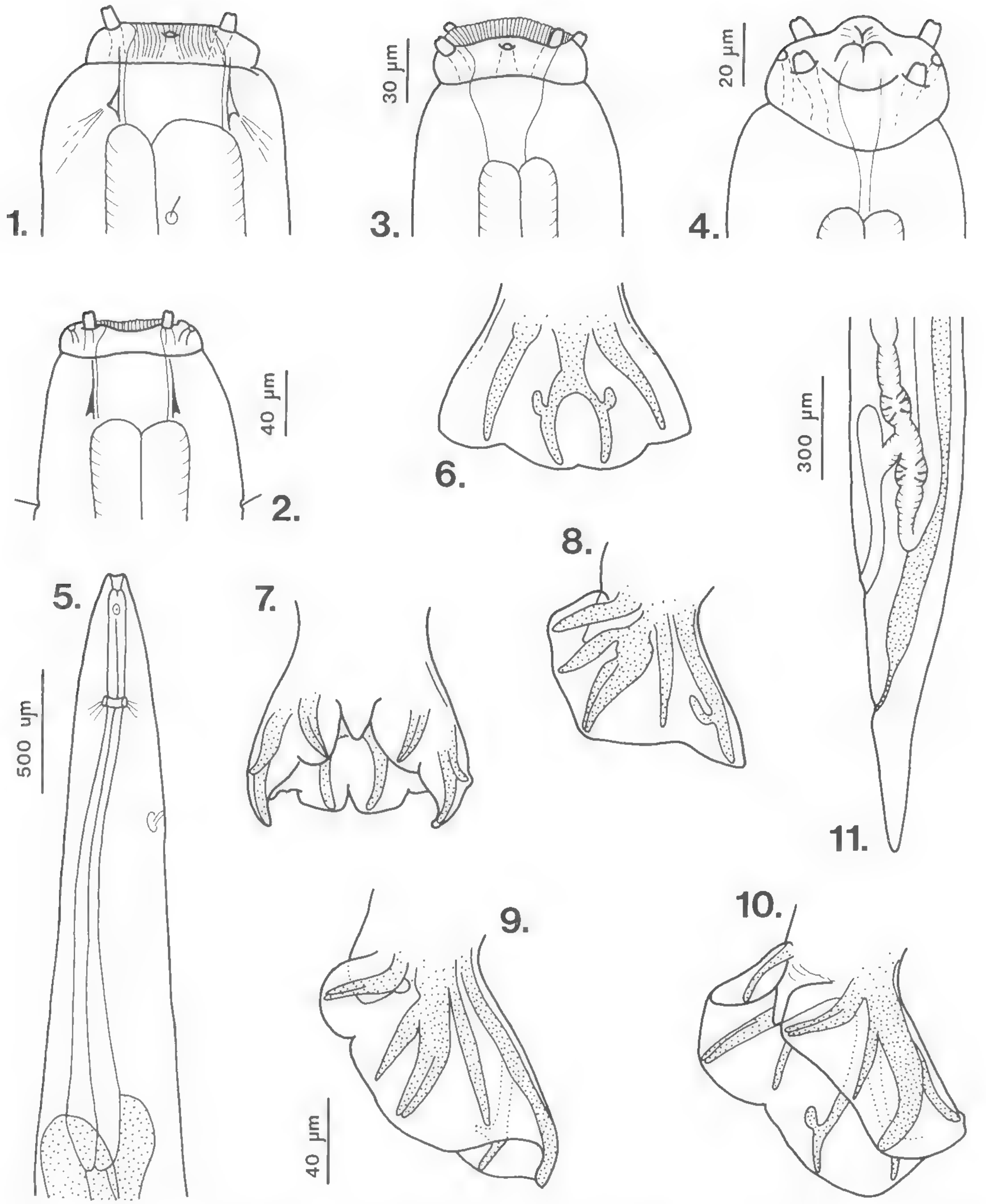

Figs. 1-11. *Alocostoma clelandi*: 1, head, lateral view. 2, head, ventral view. 3, head with circumoral cuticle raised as a frill. 4, head with mouth closed and lips pursed. 5, anterior end. 6-8, bursa in dorsal, ventral and lateral views. 9-10, lateral and subventral views of bursa of specimens from W.A. 11, posterior end of female.

TABLE 1.

Measurements of Alocostoma clelandi *from various hosts and localities. Measurements in μm unless otherwise stated.*

	Macropus giganteus		*Macropus robustus*		
	Victoria	N.S.W.	N.S.W	W.A.	
				host 1	host 2
♂ Length (mm)	14.2–17.11	11.5	11.0–13.5	6.5–10.3	15.0
Oesophagus	1600–2100	1900	1700–1950	1600–2100	1900
Length/oesophagus	7.4–8.8	6.0	6.4–7.4	3.3–4.7	7.0
Anterior end—nerve ring	500–660	580	540–570	410–480	570
—cervical papillae	120–660	–	120–135	130–145	170
—excretory pore	920–1150	700	810–950	580–720	800
Spicules	1700–1900	1780	1700–1800	1700–1800	1900
Length/spicule	8.3–9.4	6.5	6.5–7.5	3.8–5.7	7.8
♀ Length (mm)	17.0–22.2	11.7	11.9–14.3	8.4–10.8	10, 17
Oesophagus	1750–2400	1500	1950–2200	1800–2350	2100, 2400
Length/oesophagus	8.3–9.4	7.8	5.6–6.6	4.6–6.0	5.0, 7.1
Anterior end—nerve ring	450–700	500	510–530	450–500	500, 550
—cervical papillae	130–135	90	105–130	135–140	150, 150
—excretory pore	800–1200	740	830–980	650–700	750, 810
Tail	360–700	420	500–510	350–390	500, 550
Posterior end—vulva	700–1300	780	900–1000	490–650	900, 950

some specimens. When most clearly seen, very thin except for projecting ring near base, apparently for attachment of muscles (Fig. 1).

Oesophagus long, cylindrical with elongate terminal bulb, and surrounded between one quarter and one third of its length by nerve ring. Excretory pore lies at mid oesophageal length, and setiform cervical papillae lie shortly behind buccal capsule. Spicules long, alate. Gubernaculum present. Bursa large, its lobes not clearly demarcated, and short ventral lobes not joined; genital cone small, conical, with lateral swellings and with accessory cone of two short bilobed processes. Figs 6–8 show the shape of the bursa and the arrangement of the bursal rays in specimens from *Macropus giganteus* and in those from *M. robustus* in N.S.W. In males from *M. robustus* from W.A. the dorsal lobe is longer and the dorsal ray correspondingly elongated (Figs 9, 10).

Female body tapers in region of vulva, and again near tip of tail. Length of vagina varies, in specimens from eastern Australia it is shorter than in most of those from W.A. In all specimens there is a distinct anterior caecum from the point of origin of vagina (Fig. 11).

No specimens held eggs in the vagina, though these were present in the uteri. In three specimens eggs had been laid into a brown egg case, still attached to the worms. These eggs measured 105 x 50 μm, were thin shelled, and appeared not to have divided.

Unless otherwise indicated, specimens figured were from *M. robustus*, Rivertree, N.S.W. These were more numerous than those from the type host in Victoria, and were collected much closer to the type locality.

Measurements of the specimens examined are shown in Table 1; those of specimens from different hosts and localities are shown separately; although the dorsal lobe and ray is longer in those from W.A., there does not appear to be grounds for the proposal of a new species. Measurements of specimens from the two hosts in W.A. are given separately, as it seemed that one collection was of younger worms—the body is shorter and no eggs were present in the uteri.

Acknowledgments

The material described in this paper from Victoria and from Rivertree, N.S.W. was collected by Dr Ian Beveridge and other collectors from the School of Veterinary Science, University of Melbourne. The material from W.A. was collected by Dr Laurel Keller, Field Museum, Chicago, U.S.A. I am very grateful for all this help.

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ON THE PHYLOGENETIC SIGNIFICANCE OF SPERMATOZOAL MORPHOLOGY AND MALE REPRODUCTIVE TRACT ANATOMY IN AUSTRALIAN RODENTS

BY W. G. BREED & V. SARAFIS

Summary

Spermatozoa of Pseudomys nanus, P. hermannsburgensis, P. higginsi, P. australis, P. apodemoides, Leporillus conditor, Uromys caudimaculatus, Meloyms littoralis, M. cervinipes and Conilurus penicillatus are similar, having a head with three hooks and very prominent midpieces. In Zyzomys argurus, Z. woodwardi and Hydromys chrysogaster only two hooks could be seen. Spermatozoa morphology of Notomys sp. is variable. N. alexis had a short top hook and small, truncated, lower hook, whereas the sperm of N. mitchelli were either similar with a longer top hook or had three short straight hooks. All Rattus species had spermatozoa with a single much longer and more attenuated hook and a longer midpiece.

ON THE PHYLOGENETIC SIGNIFICANCE OF SPERMATOZOAL MORPHOLOGY AND MALE REPRODUCTIVE TRACT ANATOMY IN AUSTRALIAN RODENTS

by W. G. BREED* & V. SARAFIS†

Summary

BREED, W. G. & SARAFIS, V. (1978) On the phylogenetic significance of spermatozoal morphology and male reproductive tract anatomy in Australian rodents. *Trans. R. Soc. S. Aust.* **103**(5), 127-135, 31 August, 1979.

Spermatozoa of *Pseudomys nanus, P. hermannsburgensis, P. higginsi, P. australis, P. apodemoides, Leporillus conditor, Uromys caudimaculatus, Melomys littoralis, M. cervinipes* and *Conilurus penicillatus* are similar, having a head with three hooks and very prominent midpieces. In *Zyzomys argurus, Z. woodwardi* and *Hydromys chrysogaster* only two hooks could be seen. Spermatozoa morphology of *Notomys* sp. is variable. *N. alexis* had a short top hook and small, truncated, lower hook, whereas the sperm of *N. mitchellii* were either similar with a longer top hook or had three short straight hooks. All *Rattus* species had spermatozoa with a single much longer and more attenuated hook and a longer midpiece.

The morphology of the male reproductive tracts of *P. australis, Z. argurus, M. littoralis, Rattus fuscipes* and *H. chrysogaster* is similar. Testes lie in scrotal sacs and large seminal vesicles are present. By contrast, the morphology of the reproductive tracts of *Notomys* species is considerably different: their testes are smaller, usually naturally cryptorchid, and seminal vesicles are barely visible to the naked eye although large ventral prostates occur. The phylogenetic implications of the findings are discussed.

Introduction

There is controversy over the phylogenetic relationships of Australian native rodents (Tate 1951; Simpson 1961; Watts 1974; Baverstock *et al.* 1977b; Baverstock *et al.* 1977c) although all species are considered members of the Muridae.

On the basis of a wealth of morphometric data, Tate (1951) classified the Australopapuan rodents into two subfamilies: the Hydromyinae, which he considers diverged from an ancestral murid or even cricetid stock and is represented in Australia by *Xeromys* and *Hydromys*, and the Murinae which includes all other genera. In the Murinae he considers that *Pseudomys, Leporillus, Mastacomys, Notomys, Zyzomys* and *Conilurus* evolved from one ancestral stock, whereas a more modern group branched off from a stem leading to *Rattus* and gave rise to *Melomys* and *Uromys*. Simpson (1961) identified four groups, two subfamilies (the Hydromyinae and Pseudomyinae) and two other groups: one of *Rattus* species and the other of *Uromys/Melomys*. Of these the Pseudomyinae, which includes *Notomys, Conilurus, Pseudomys* and *Leporillus* species, as well as several other genera, has radiated mainly in Australia, whereas the other three groups are well represented in New Guinea.

Several authors have recently hypothesised phylogenetic relationships. Watts (1974) put forward a phylogenetic scheme in which *Pseudomys* and *Rattus* are closely related and *Pseudomys* was considered ancestral to all Australian rodents with the exception of *Melomys, Mastacomys* and *Rattus*. *Mastacomys* is shown diverging early from the ancestral stock, as is *Rattus* and *Pseudomys*. As a result of chromosomal analysis Baverstock *et al.* (1977b, 1977c) concluded that *Rattus* stood out as a distinct group with the Hydromyinae, and the *Uromys/Melomys* group diverged at an early stage from the ancestral stock which gave rise to the Pseudomyinae. The position of *Zyzomys* was considered enigmatic, but they

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considered that it is probably derived from the same ancestral stock that gave rise to the Pseudomyinae.

Baverstock *et al.* (1977b) concluded that sperm morphology might be a particularly useful character in gaining further evidence about the phylogeny of Australian rodents, as sperm are less likely to be related to the lifestyle of the animal than morphological characters. In this study, therefore, we present data on spermatozoal morphology, together with some other aspects of the male reproductive tract anatomy, from representatives of the main groups of Australian native rodents.

Materials and Methods

Animals: Rodents used in the present study were obtained from the following sources:

The hopping mice (*Notomys alexis*) and plains mice (*Pseudomys australis*) were derived from a laboratory stock maintained at the Medical School, University of Adelaide (see Breed 1975).

The water rat (*Hydromys chrysogaster*) was obtained from the River Torrens near Adelaide; *Rattus fuscipes greyi* was collected near Stirling, S.A., *Pseudomys hermannsburgensis* was laboratory bred from parents collected near Curtin Springs, N.T., and *Zyzomys argurus* and *Zyzomys woodwardi* were collected near Darwin by Dr R. Begg.

Material from the following species was obtained from animals held at the Institute of Medical & Veterinary Science field station in Adelaide: *Pseudomys higginsi, P. apodemoides* (see Baverstock *et al.* 1977a for specific terminology), *P. nanus, Conilurus penicillatus, Leporillus conditor, Melomys littoralis, M. cervinipes, Uromys caudimaculatus, Rattus leucopus leucopus, R. sordidus, R. colletti, R. lutreolus* and *Notomys mitchellii* (for details of sites of capture see Baverstock *et al.* 1977b, 1977c, Robinson *et al.* 1978). Nomenclature of *Rattus* spp. used is that of Robinson *et al.* 1978.

Preparation of spermatozoa: Spermatozoa from 1 *Hydromys chrysogaster*, 4 *M. littoralis*, 6 *N. alexis*, 1 *P. apodemoides*, 4 *P. australis*, 1 *P. hermannsburgensis*, 3 *R. fuscipes greyi* and 4 *Z. argurus* were obtained immediately after killing the animals with chloroform. The tail of one epididymis and adjacent vas deferens was dissected out and sperm droplets squeezed onto several slides. Thin smears were made by using the edge of another slide. Spermatozoa from the other species were obtained after anaesthetising the animals with urethane. A small incision was then made in one scrotal sac and part of the tail of one epididymis was removed from which sperm smears were obtained as described above. After allowing the smears to dry, they were flooded with 2.5% glutaraldehyde in 0.01M sodium cacodylate fixative and a coverslip placed on top which was fixed in position with De Pe X to give a semi-permanent mount. Latterly wet smears were fixed with either glutaraldehyde or picric acid/glutaraldehyde/formaldehyde mixture (see Ito & Karnovsky 1968).

Methods of assessment of spermatozoa: Smears were inspected by phase contrast and spermatozoa that appeared intact, straight, and reasonably well isolated, were selected for measuring. Using an eyepiece micrometer the following measurements were made: (1) head length from the most caudal part of head to top of the curve (see Braden 1959), (2) length of midpiece, and (3) length of remainder of tail (usually the principal and end pieces were not well differentiated, so they were included together as one measurement). Several spermatozoa from each individual were observed and usually the measurements were similar or identical. When some variation occurred the range has been included (Table 1).

Smears were also observed by Nomarski differential interference microscopy, and selected spermatozoa photographed. Measurements obtained by phase contrast were compared with those made from photographs obtained by Nomarski.

Attempts were made to determine the presence of the acrosome and the distribution of DNA in the sperm head from *P. australis, M. littoralis, N. alexis, Z. argurus* and *H. chrysogaster*. The DNA was determined according to the Feulgen method (Pearse 1968) and by the use of DAPI (Russell *et al.* 1975). After staining by the Feulgen method smears were observed by epifluorescence using green excitation (Ploem 1967) (Olympus excitation filter IF 545, with a G dichroic mirror and barrier filter Y595) and by normal bright field microscopy. When DAPI in distilled water (about 0.001%) was used the filter system included ultraviolet excitation (UG 1), U dichroic mirror, and Y455 barrier filter. Acridine orange was used in an attempt to visualise the acrosome by fluorescence microscopy (see

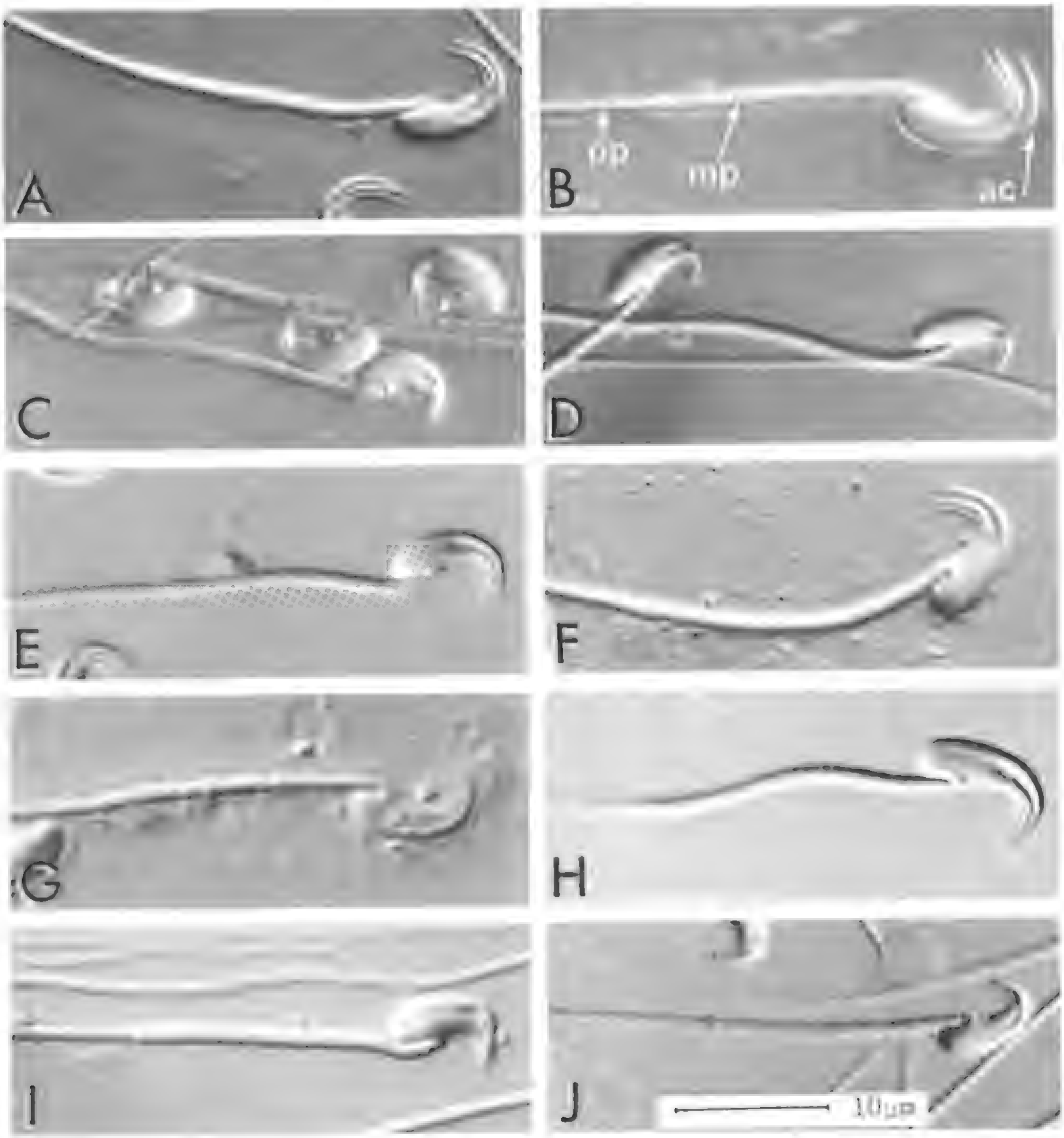

Fig. 1. Spermatozoa: A. *Leporillus conditor*; B. *Uromys caudimaculatus*; C. *Conilurus penicillatus*; D. *Zyzomys argurus*; E. *Pseudomys higginsi*; F. *P. hermannsburgensis*; G. *P. nanus*; H. *P. australis*; I. *P. apodomoides*; J. *Hydromys chrysogaster*. mp = midpiece pp = principal piece ac = acrosome

Bishop & Walton 1960). For this, blue excitation (BG 12), B dichroic mirror, and Y455 barrier filter were used.

Body, testis and accessory organ weights: Some of the animals from which spermatozoa were obtained were weighed and one testis, seminal vesicles together with coagulating glands if present, and ventral prostates were also removed and weighed after removing adherent fat from the organs. The weight of a single testis was doubled to give an approximate weight of the paired testes.

Results

Spermatozoal morphology

Figs 1 & 2 and Table 1 show the morphology of the head and mid-piece of spermatozoa from the various species. Intra-individual

TABLE 1

Comparative head and tail lengths of spermatozoa from various Australian native rodents.

Species	Size of spermatozoa (μm) Length of head*	Mid-piece	Principal and end piece	Total length
Conilurus penicillatus	7	20–22	96	123–125
Hydromys chrysogaster	7	20	88	115
Leporillus conditor	9	23	78	110
Melomys littoralis	8	22	80	110
Notomys alexis	5–8	25–27	70	100–105
N. mitchellii	9	24	65	98
Pseudomys apodemoides	8	22	90	120
P. australis	9	23	88–93	120–125
P. hermannsburgensis	8–10	23	85	116–118
P. higginsi	8	20–22	70–85	98–115
P. nanus	9	22	96	127
Rattus colletti	12	51	95	158
R. fuscipes greyi	12	48	102	162
R. l. leucopus	12	135		147
R. lutreolus	13–15	54	95	162–164
R. sordidus	12	45–50	95	152–157
Uromys caudimaculatus	8–10	20	72–82	100–112
Zyzomys argurus	7	22	108	137

* From base to top of curvature of hook.

variation was small except for sperm from *Notomys alexis* and *N. mitchellii.*

Sperm from all species, apart from *Rattus* spp. and *Notomys* spp. conformed to the same general pattern. The sperm head had a fairly broad base which tapered to two or three prongs or hooks. The top hook was usually larger and invariably single, whereas the lower one was often bifid. There was inter-specific variation in head length (Table 1). Staining with Feulgen and DAPI demonstrated that the top prong consisted of DNA, and Acridine orange indicated the presence of an acrosome covering the nuclear material on top of the hook and extending beyond its tip. The lower hook(s) appeared to have DNA only at the base and no orange or red colour was obtained with Acridine orange.

About one-third the way up the ventral side of the sperm head a small spike occurred to which is attached the connecting piece. On the dorsal side, a ridge could sometimes be seen which stained orange with Acridine orange, and presumably represent the continuation of the acrosome down the dorsal side of the head. The midpiece had very prominent gyres of mitochondria.

Species that conform to the above general pattern and had three hooks included *Leporillus conditor, Pseudomys hermannsburgensis, P. australis, P. higginsi, P. nanus, P. apodemoides, Conilurus penicillatus, Melomys littoralis, M. cervinipes* and *Uromys caudimaculatus.* These spermatozoa were similar except that the length of the head of *C. penicillatus* was shorter. *Melomys littoralis* and *M. cervinipes* had smaller hooks, and only on close examination were three discernible. *Zyzomys argurus, Z. woodwardi* and *Hydromys chrysogaster* had spermatozoa of the same basic structure but the hooks were not so long and only two were visible. No bifid lower prong could be seen. The sperm heads tended to be shorter than most of those with the three hooked sperm, and the breadth of the sperm head was also less. *H. chrysogaster* also had a relatively short midpiece.

The spermatozoa from *Notomys alexis* were variable but consistently different. Fig. 2 shows three different morphological types. The head length was generally short and there was usually a short top hook and a very truncated lower hook. Only the top hook appeared to be surrounded by an acrosome. The midpiece of *N. alexis* was generally longer than that for other species described above (see Table 1), but the principal/end piece appeared shorter. *N. mitchellii* also had intra-individual variable spermatozoal morphology. Sometimes there was a single top hook which was longer than in *N. alexis* and a short truncated lower hook, whereas on other occasions, two or three straight short hooks occurred.

The spermatozoa of all *Rattus* species were markedly different from those described and generally appeared similar to each other and to *R. norvegicus* and *R. rattus* (Friend 1936). The heads were long and attenuated with a long sharp hook. Acridine orange demonstrated the acrosome primarily on the top surface of the sperm head and extending beyond the DNA to the tip of the hook. The junction between the mid and principal piece was not easily visible, in contrast to the situation in the previous species described, but when visible it appeared that the midpiece was at least twice as long as that for sperm from the other groups of Australian rodents. Since the principal and end pieces were generally similar

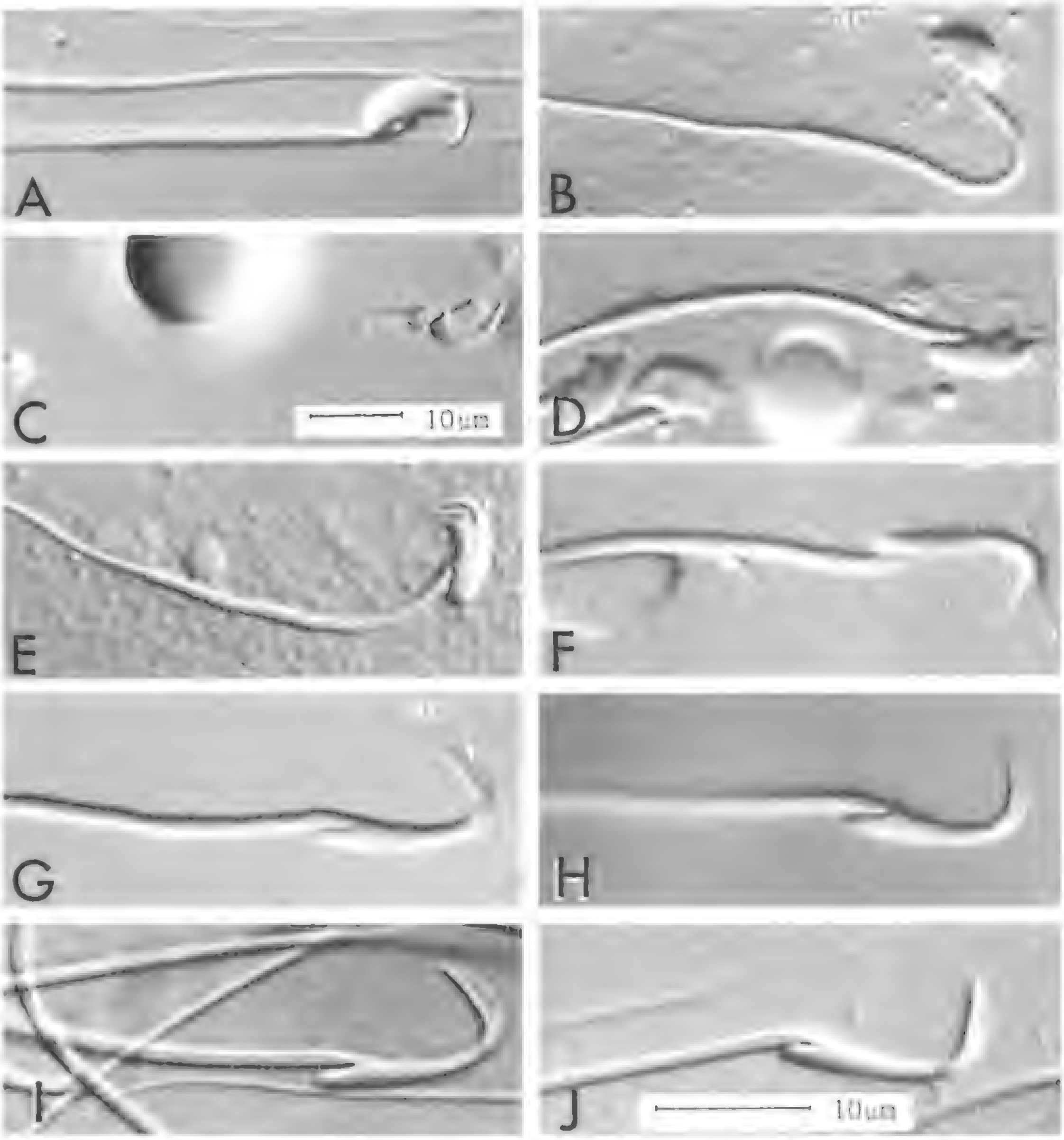

Fig. 2. Spermatozoa: A. *Melomys littoralis;* B. *Notomys alexis*; C. *N. alexis*; D. *N. alexis*; E. *N. mitchellii*; F. *Rattus sordidus*; G. *R. colletti*; H. *R. l. leucopus*; I. *R. fuscipes greyi*; J. *R. lutreolus.*

in lengths to those of the other groups, except for *N. alexis,* the resultant total length of the sperm was considerably greater.

Testis and male accessory organs

Analysis of gonadal weights has been performed on some of the species of animals that yielded motile sperm. Table 2 demonstrates that testis weight/g body weight was similar in *P. australis, R. fuscipes greyi, M. littoralis* and *H. chrysogaster* in spite of the considerable range of absolute body weights (60–540 g). The relative testis weight of *Z. argurus* was somewhat less and those of *N. alexis* and *N. mitchellii* were markedly lower than in the other species examined (Table 2).

The testes of *P. australis, R. fuscipes, M. littoralis, H. chrysogaster* and *Z. argurus* invariably occurred in a scrotal sac with the tail of the epididymis protruding into an extension of this towards the body wall of the scrotum.

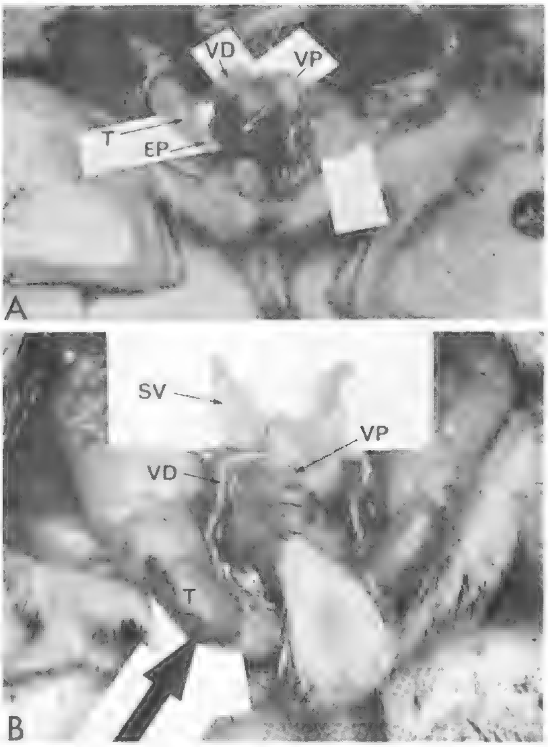

Fig. 3. Male reproductive tracts: A. *Notomys alexis;* B. *Zyzomys argurus.* T = testis, VD = vas deferens, SV = seminal vesicle, EP = tail of epididymis, VP = ventral prostate.

By contrast, the testes of *N. alexis* and *N. mitchellii* appeared to usually be naturally cryptorchid and lay in the abdomen close to the body wall ventral to the tail. Externally the skin of *Notomys* species (and other species) was usually pigmented and only sometimes a slight swelling occurred. The tail of the epididymis lay in a small cremastic sac.

The relative weights of the male accessory organs of *R. fuscipes, M. littoralis, H. chrysogaster,* and *P. australis* were similar. Seminal vesicles, together with coagulating glands when present, ranged from 0.4 to 1.8% of total body weight, and those for ventral prostates 0.06–0.31%. The relative weights of seminal vesicles and coagulating glands for *Z. argurus* were somewhat less (0.3%–0.5%), although that of the ventral prostate was similar. The morphology of the seminal vesicles of *Z. argurus* (Fig. 3) differed somewhat from that of the other species. *N. alexis* and *N. mitchellii* had seminal vesicles that were only just visible to the naked eye. They measured about 3 mm in maximum diameter. Coagulating glands could not be found on macroscopic dissection, but the relative weights of the ventral prostates were considerably greater than those for the other species examined except for *R. fuscipes.* Development of the ventral prostate occurs rapidly at around the time of puberty

TABLE 2

Body and male reproductive organ weights of some Australian native rodents.

Species	No. of animals	Body wt (g)	Testis wt (mg)	Seminal vesicle and coagulating gland wt (mg)	Ventral prostate wt (mg)
Hydromys chrysogaster	1	536	12460*** (2.3%)	2378 (0.4%)	**
Melomys littoralis	3	61 ± 3	1684 ± 62 (2.6–3.0%)	700 ± 14 (1.0–1.3%)	63 ± 9 (0.08–0.1%)
Notomys alexis	4	29 ± 2	33 ± 9 (0.17–0.07%)	—*	97 ± 20 (0.20–0.46%)
N. mitchellii	2	33 ± 2	61 ± 5 (circa 0.2%)	—*	79 ± 3 (c. 0.2%)
Pseudomys australis	3	59 ± 6	1739 ± 362 (3.0–4.5%)	1000 ± 94 (1.4–1.8%)	60 ± 9 (0.06–0.16%)
Rattus fuscipes	3	100 ± 21	4410 ± 231 (3.4–6.1%)	1270 ± 186 (1.0–1.6%)	247 ± 38 (0.29–0.31%)
Zyzomys argurus	3	53 ± 11	400 ± 49 (0.4–1.1%)	185 ± 27 (0.3–0.5%)	43 ± 3 (0.07–0.13%)

* Seminal vesicles and coagulating glands are vestigeal in *Notomys* species. Maximum diameter of about 3 mm.
** Not weighed.
*** Range of ratios of organ weights to total body weights expressed as percentage.

(Breed 1979) and is therefore likely to be androgen dependant.

Discussion

Spermatozoa from the Australian rodents investigated fell into three groups. Those from single species of *Conilurus*, *Leporillus*, *Uromys*, *Hydromys*, the two species of *Zyzomys* and *Melomys* and the five species of *Pseudomys* were all similar to each other. Most had a sperm head with three hooks, and observations of only two may reflect problems of technique. The top hook was invariably made up of DNA over which an acrosome occurred, whose material stained orange with Acridine orange. This appears to coincide with the hook observed in many other murid rodents (e.g. Friend 1936; Bishop & Walton 1960). However, the lower, usually bifid, hook appears to be a unique character occurring in Australian rodents and is presumably derived. This hook appears to only have DNA at its base, and is likely to be made up mainly of acrosomal material, even though it does not stain orange or red with Acridine orange. Variability of staining of acrosomal material with Aridine orange has previously been documented (Allison & Hartree 1970). It seems likely, therefore, that all the above genera have been derived from the same ancestral form in which a two or three-hooked sperm evolved.

The sperm morphology of *Notomys* species is, however, markedly different. In *N. alexis* and *N. mitchellii* there was much individual variability in sperm morphology. Generally, however, the sperm of *N. alexis* was characterised by a single small truncated top hook. Using Nomarski optics, it appeared that this was covered by an acrosome which did not, however, appear to fluoresce orange or red with Acridine orange. The lower hook in this species was short, truncated, and at times barely recognisable, and thus may represent the DNA staining area of the lower hooks occurring in the other genera. In *N. mitchellii* a longer top hook was visible and this sometimes appeared to be the only well-defined hook. Most sperm had three hooks (as in the Pseudomyinae and other groups) but they appeared shorter with a sharper angle of curvature. It is likely, therefore, that the lack of well defined hooks in *N. alexis* is a secondarily derived form from an ancestral two or three pronged Pseudomyid-like sperm. In *N. alexis* the total length of the head and the relative proportions of the midpiece to the rest of the sperm tail was also considerably different from all the other genera. In *Notomys*, in contrast to the other species studied, there appeared to be relatively few spermatozoa in the epididymis and vas deferens, the ratio of testis weight/total body weight was markedly less, the testes usually appeared naturally cryptorchid, the seminal vesicles and coagulating glands markedly smaller and the ventral prostate relatively larger. Vaginal plugs, after recent matings, have not yet been observed in *N. alexis*. This may be due to lack of development and secretion of the seminal vesicles and coagulating glands. Other physiological and behavioural significances of these differences have yet to be elucidated, but the smaller testes and few stored sperm suggest only infrequent matings would result in successful fertilizations. The social-sexual behaviour of these species is not known in detail but it appears that *Notomys alexis* is a highly social animal (Stanley 1970). An anatomical feature that may be related to this is the occurrence of prominent chest glands (Stanley 1970, Watts 1975). We therefore suggest that *Notomys* has diverged further from the basic pseudomyid stock than suggested on morphological characters by Tate (1951). Further studies on spermatozoal and male reproductive tract morphology of the other *Pseudomys* and *Notomys* species should be carried out to determine if our findings are characteristic of the genera. This may not be the case as Illison[1] (1971) states that not all *Pseudomys* species have spermatozoa of similar morphology, although she considers that only two hooks are normally present. She claimed that spermatozoa of *P. shortridgei* represented the primitive sperm type and *P. delicatula* (as *Leggadina delicatula*) sperm had no hooks. Unfortunately we have not been able to reinvestigate these findings.

The spermatozoa of *Rattus* spp. were very different from those of all other Australian rodents and similar to congeners occurring on other continents. Illison[1] came to a similar conclusion. This suggests an independent line of evolution and invasion into Australia of *Rattus*. Lidicker (1968) suggested, from comparative morphological studies of the penis, that there were two rodent invasions into New Guinea—one that gave rise to all rodents

[1] Illison, L. Abstract presented at Aust. Mammal Society Meeting, Vol. 2, No. 8, December, 1971.

except *Rattus* and the other that gave rise to the "native" species of *Rattus*. More recently Baverstock *et al.* (1977b, 1977c), from chromosomal data, concluded similarly for the Australian rodents. Our data on sperm morphology therefore supports the phylogenetic conclusions of these authors, but conflicts with those of Tate (1951) who regarded the Hydromyinae as a separate subfamily and Simpson (1961) who regarded the Hydromyinae and Pseudomyinae (excluding *Rattus*) as separate subfamilies.

The significance of interspecific differences in sperm morphology has been discussed by Friend (1936), Fawcett (1970, 1971, 1975, 1977) and others. Some mammal spermatozoa have large acrosomes, e.g. guinea pigs (Fawcett 1970) and musk shrews (Green & Dryden 1976). The latter relate this to the thick corona radiata around the eggs. Acrosomes of spermatozoa of the Pseudomyinae/Hydromyinae/*Uromys*/*Melomys* stock were not very well developed, whereas those of the *Rattus* spp. were similar to that of the laboratory rat.

The sperm head is very rigid, which may be necessary for penetration of the thick zona around the egg (Bedford & Calvin 1974), whereas the hook of murid sperm may be involved in motility (Cohen 1977). However, head shape does not appear to be closely related to species specificity for penetration of the oocytes, as human sperm can penetrate hamster eggs (Rudak *et al.* 1978). Fawcett (1977) has suggested that the hook may deflect the sperm from the surface of the mucosal lining in the oviduct but as yet there appears to be no evidence for this.

The midpiece also differs greatly between species. Occurrence of increased mitochondrial development of the midpiece correlates with the evolution of internal fertilization (Afzelius 1971; Fawcett 1978), but variation in number and shape of mitochondria between species of mammals has not yet been given any satisfactory explanation. There is no obvious correlation between number of mitochondria and the distance sperm have to swim to bring about fertilization. Thus although there is as yet no agreed explanation for either sperm head shape or midpiece length in mammalian spermatozoa, these characters may be useful in determining phylogenetic similarities and differences when taken into consideration with other morphological, biochemical, cytological and behavioural characteristics.

Acknowledgments

We should specially like to thank Drs Chris Watts and Peter Baverstock for making available to us many of their valuable rodents and for criticising the manuscript, Dr Begg for supplying us with *Zyzomys* spp., Dr Possingham of CSIRO for permitting us the use of his Nomarski microscope, Mr R. Murphy, Mrs J. Brazier and Mrs B. Sheldon for assistance in preparing the manuscript. We should also like to thank the National Parks & Wildlife Services for permits to catch *Hydromys* and *Rattus fuscipes* in South Australia and *Notomys alexis* and *Pseudomys hermannsburgensis* in the Northern Territory.

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ASPECTS OF GROWTH AND FEEDING IN GOLDEN CARP, CARASSIUS AURATUS, FROM SOUTH AUSTRALIA

BY B. D. MITCHELL

Summary

Age and growth were determined in populations of Carassius auratus from the River Murray, Millbrook Reservoir, and a farm dam. Fish from Millbrook grew most rapidly, reaching 13.1 cm at the end of the first year's growth. The Uraidla population exhibited the lowest growth rate, reaching 4.7 cm at the end of the first year. Significant differences in length-weight relationships occurred between all populations. The length (l) –weight (w) equations were: Millbrook, $w = 0.029l^{3.141}$ (r^2 = 0.989); Cobdogla, $w = 0.014l^{3.265}$ (r^2 = 0.923); Uraidla fish (< 6 cm), $w = 0.024l^{3.302}$ (r^2 = 0.950), Uraidla fish (> 6 cm), $w = 0.054l^{2.759}$ (r^2 = 0.908).

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Summary

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Age and growth were determined in populations of *Carassius auratus* from the River Murray, Millbrook Reservoir, and a farm dam. Fish from Millbrook grew most rapidly, reaching 13.1 cm at the end of the first year's growth. The Uraidla population exhibited the lowest growth rate, reaching 4.7 cm at the end of the first year. Significant differences in length-weight relationships occurred between all populations. The length (l) –weight (w) equations were: Millbrook, $w = 0.029l^{3.143}$ ($r^2 = 0.989$); Cobdogla, $w = 0.014l^{3.265}$ ($r^2 = 0.923$); Uraidla fish (< 6 cm), $w = 0.024l^{3.302}$ ($r^2 = 0.950$), Uraidla (fish > 6 cm), $w = 0.054l^{2.739}$ ($r^2 = 0.908$).

Food items from Millbrook and Uraidla fish consisted of benthic microorganisms and detritus. Growth and feeding is discussed in relation to other introduced cyprinids in Australia.

Introduction

Ecological studies of introduced freshwater fish in Australia have concentrated on salmonid species due to their importance in commercial and amateur inland fisheries (Lake 1957; Weatherley 1958; Weatherley & Lake 1967; Tilzey 1970). The cyprinids: the European carp, *Cyprinus carpio,* the tench, *Tinca tinca,* and the golden carp or goldfish, *Carassius auratus,* have received little attention as they have not generally been regarded of commercial interest.

The history of the introduction and subsequent spread of European carp through south-eastern Australia is now well documented (Weatherley & Lake 1967; Anon. 1971; Anon. 1975; Shearer 1977; Wharton 1977). The detrimental effects on water quality, plants and animals ascribed to the European carp are manifold (Butcher 1962; Anon. 1975). It is only comparatively recently, however, that studies on the basic biology and ecology of this species have commenced in Australia (Lake 1966; Jones 1974[1]; Reynolds 1976a; Shearer 1977). Although apparently destructive in small, crowded habitats, it may not compete with native fishes (Shearer 1977) nor be directly responsible for the decline in catches of most native species in the River Murray (Weatherley & Lake 1967; Reynolds 1976b).

Weatherley & Lake (1967) have recorded the introduction and distribution of the tench in southeastern Australia, and this species was fairly common in the Murray and Torrens Rivers in South Australia (Scott, Glover, & Southcott 1974). The tench appears to have been displaced in the lower Murray by the European carp (Reynolds 1976b). The food and growth of wild populations of tench in Tasmania have been studied by Weatherley (1959, 1962), and some information is available on tench growth at Narrandera (Weatherley & Lake 1967).

The golden carp was introduced to Victorian streams about 1876 (Scott, 1953; Lake 1959) and spread to South Australia via the River Murray (Scott 1953). This species is widespread throughout South Australia (Scott et al. 1974) and was "quite prolific" in streams near Adelaide (Scott 1953). Golden carp is also widely distributed in Queensland and Western Australia (Weatherley & Lake 1967; Lake 1971) and, like the other cyprinids,

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[1] JONES, W. (1974) Age determination and growth studies of four species of fish from the River Murray. Unpublished Hons Thesis, Department of Zoology, University of Adelaide.

appears to prefer sluggish waters (Weatherley & Lake 1967; Scott *et al.* 1974).

Golden carp may be caught in "very large numbers" in Victorian backwaters (Anon. 1971), the Albury-Wodonga area (Walker & Hillman 1977), and in South Australia. This species may increase water turbidity in a fashion similar to European carp (Lake 1966). Golden carp might be expected, therefore, to exert similar, although less pronounced, environmental effects to European carp in those sheltered backwaters where the latter is likely to have its most profound effect.

This paper presents information on growth in three populations of golden carp from differing habitats in South Australia. Gut contents of fish from two of these localities are also analysed and the results discussed in relation to other cyprinids in Australia.

Methods

Three populations of golden carp from divergent habitats were sampled using a seine net (3 cm stretched mesh), dip nets, and a cylindrical trap (12 cm aperture, 1.0 mm mesh size).

Thirty-two fish were collected from a small (100 x 40 m), shallow (0.75 m) backwater of the River Murray at Cobdogla, S.A. (140°24′E, 30°14′30″S) in late September 1977. The backwater was enclosed on three sides by dense stands of cane grass (*Phragmites* sp.), the open water underlain by soft, fine sediments.

Thirty-eight fish were collected in March 1978 from Millbrook Reservoir, surface area 178 ha and mean depth 9.3 m, in the Mt Lofty Ranges (138°48′45″E, 34°49′44″S). The reservoir has gently sloping sides, a gravel and clay substrate, and small, localised stands of water ribbon (*Triglochin procera*).

One hundred and thirty-six fish were collected from a small (300 m^2), deep (3–4 m) farm dam near Uraidla, Mt Lofty Ranges (138°30′50″E, 34°48′S) in March and April 1978. The bore-fed, clear-water dam has a gravel and clay substrate and was bounded on the southwestern perimeter by a narrow stand of bullrush (*Typha* sp.). The entire pond bottom was covered with a dense, submerged stand of ribbon weed (*Vallisneria spiralis*).

Fish were treated as follows. Live weight (gm) and standard length (cm) were measured. Six large, symmetrical scales were removed from the left side of the body between the lateral line and the anterior half of the dorsal fin (after Tesch 1968). Scales were cleaned and examined microscopically using transmitted light. Annuli were determined after Tesch (1968). A radius from the nucleus to the middle-front margin of a non-regenerated scale was measured using a micrometer eyepiece, and the distance from the nucleus to each annulus was also measured. The digestive tracts of 70 fish from Millbrook and Uraidla were removed and their lengths measured. Representative samples of material in the intestine were taken from the fore, mid, and hind gut. This material was examined microscopically and analysed, using the occurrence and points methods (Hynes 1950). The intestines of fish from Cobdogla had been evacuated before examination.

Results

Age and Growth: The length-frequency distribution of each population sample is presented in Figure 1. It can be seen that the length ranges of all samples overlap to some degree. Skewness is not marked in any instance, suggesting that samples were representative. The mean length and weight of each population sample are presented in Table 1. Mean lengths for Cobdogla and Millbrook population samples were similar although the length-frequency distribution indicates that fish longer than 18 cm were more common from Millbrook. Fish from Uraidla were markedly shorter than from Cobdogla and Millbrook. Mean weight was highest for the Millbrook population sample and, as for length, lowest for fish from Uraidla.

Log live weight has been plotted against log standard length for each population in Figure 2. The relationship between standard length

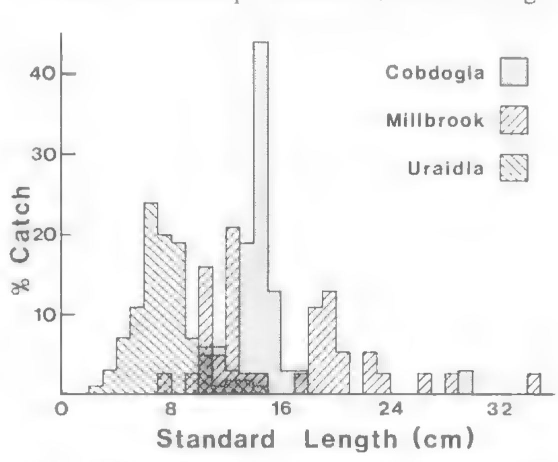

Fig. 1. Length-frequency distribution of catches

TABLE 1.
Live weight and standard length statistics of catches.

Statistic	*Cobdogla*	*Millbrook*	*Uraidla*
n (sample size)	32	38	136
Mean live weight (gm)	83.0	152.8	12.4
S.D.	1.76	3.01	2.16
Range	37.9–1172.2	15.0–2046.4	0.6–84.0
Mean standard length (cm)	14.3	15.4	7.1
S.D.	1.18	1.42	1.32
Range	10.1–29.3	7.4–34.4	2.6–14.3

(l) and live weight (w) was $w = 0.014l^{3.265}$ (r^2 0.923) for fish from Cobdogla, and w $0.029l^{3.111}$ ($r^2 = 0.989$) for fish from Millbrook. The slope of the regression line for fish from Uraidla appeared to change at a length of 6 cm. The relationship was $w = 0.024l^{3.302}$ ($n = 29$, $r^2 = 0.950$) for fish less than 6 cm length, and $w = 0.054l^{2.759}$ ($n = 107$, $r^2 = 0.908$) for fish longer than 6 cm. No change in the length-weight relationship was apparent for Cobdogla or Millbrook fish. The significance of differences in the exponent b was determined by comparing the slopes of the regression lines in Figure 2. Analysis of covariance revealed significant differences (F sig. at 0.001) in b between all populations and between individuals shorter and longer than 6 cm from Uraidla. All populations appear to be undergoing allometric growth. The change in length-weight relationship for the Uraidla population reflects changes in growth rate after the formation of the first annulus.

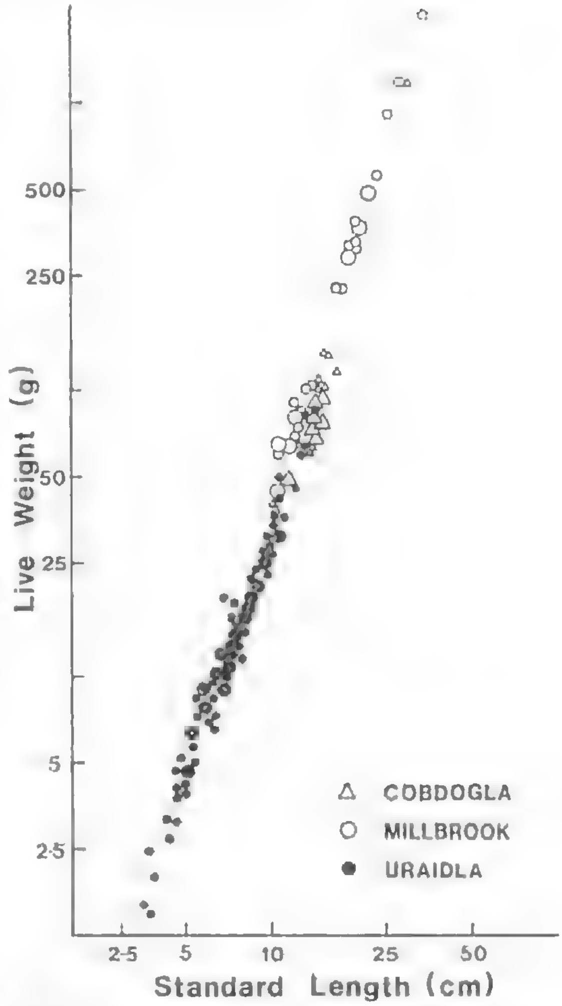

Fig. 2. Relationship of log live weight to log standard length (large symbols indicate two or more identical values).

The scales of golden carp have been described by Llewellyn (1969) who noted that the circuli of the embedded section were "fine and regular". Difficulty was experienced in the interpretation of annuli in 12% of fish; this was particularly the case for older fish.

Fish from Cobdogla, caught in September 1977, appeared to be in early growing season (a narrow band of widely spaced circuli followed the last annulus) suggesting that the annulus may have been formed in July or August of that year. Fish aged 0+, 1+ and 2+ from Millbrook and Uraidla, caught in March 1978, were apparently in early to mid-growing season. This suggested that annulus formation and spawning had taken place later in 1977 at these localities than at Cobdogla. The mean daily maximum temperature for the Cobdogla area is approximately 24°C (67% of the year with temperatures above 20°C) while the mean daily maximum in the Mt Lofty Ranges is approximately 18°C (42% of the year with temperatures above 20°C) (Bureau of Meteorology 1975).

Growth was determined by back-calculation of length at the time of formation of successive scale annuli. Scale radius is plotted against standard length in Figure 3. It was found that the data best fitted a linear relationship (r^2 0.974) when all samples were pooled ($n = 115$). The relationship of scale radius to body length was, standard length = 25 (scale radius) + 1.90. This line intercepted the length axis at 1.9 cm. Weatherley (1959) ignored an intercept of 1.7 cm in back-calculations for tench to avoid over-estimation of the

TABLE 2.
Age-frequency composition and mean back-calculated length at the end of each year.

Population	*Age group*	*No. fish*	*% catch*	*Mean length at capture*	*Mean calculated standard length (cm) at end of each year of life*									
					1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Cobdogla	0	0	0	—										
	1	3	9.4	11.4	5.8									
	2	23	71.8	14.2	8.0	12.3								
	3	5	15.6	15.0	7.3	12.3	14.6							
	4	0	0	—										
	—													
	10	1	3.1	29.3	8.9	12.9	18.3	23.8	25.3	26.0	26.9	27.5	28.0	29.1
Millbrook	0	20	52.6	11.6										
	1	10	26.3	19.2	12.9									
	2	5	13.2	21.4	11.8	18.9								
	3	2	5.3	27.5	17.8	23.3	25.7							
	4	0	0	—										
	—													
	10	1	2.6	34.4	11.7	14.7	23.2	25.0	26.6	27.7	30.1	32.4	33.5	34.4
Uraidla	0	26	57.8	4.9										
	1	16	35.6	7.0	4.4									
	2	0	0	—										
	3	2	4.4	10.5	7.2	9.6	10.1							
	4	1	2.2	10.3	5.5	7.6	9.3	10.1						

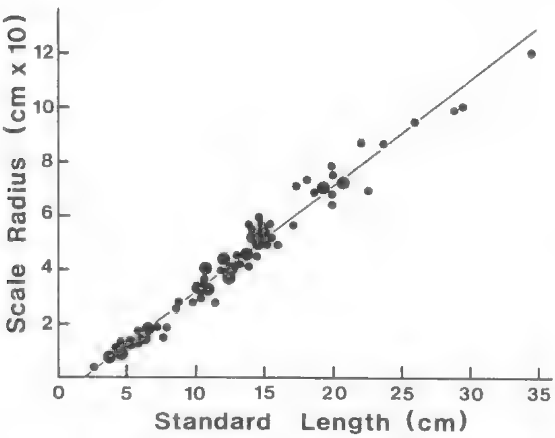

Fig. 3. Relationship of scale radius to standard length (large symbols indicate two or more identical values).

first year's growth. However, the intercept was retained in the present case as this gave a mean back-calculated length at the first annulus of 4.8 cm for fish from Uraidla and many 0+ age group fish collected from that locality approached or even exceeded that length.

The modified direct proportionality formula (Tesch 1968; Chugnova 1970) was used in the back-calculation of growth history. The age-frequency composition and mean back-calculated length at the end of each year for all samples are presented in Table 2. Mean back-calculated standard lengths and 95% confidence limits are plotted against age for all populations in Figure 4. Points without confidence limits represent individual fish. Growth curves for fast and slow growing forms of golden carp from the River Danube plotted from Kukuradze & Mariyash (1975) are also presented in Figure 4.

In all populations growth was most rapid in the first year of life, thereafter decreasing gradually. Even allowing for individual and year-class variation in growth rate, marked inter-population differences were evident. Fish from Millbrook grew most rapidly and reached 13 cm in their first year, compared with 4.8 cm for fish from Uraidla. Fish from Cobdogla exhibited intermediate growth. The growth rate of the Millbrook population was similar to that for the fastest growing form from the Danube. However, the Uraidla population had a lower growth rate than the slowest growing population from the Danube.

Feeding: Relative gut length of fish from Millbrook and Uraidla was determined as length of gut from oesophagus to anus (cm) divided by standard length (cm). Relative gut length varied considerably between individuals (range = 1.64–4.48). No inter-population differences were apparent, and no general relationship between relative gut length and body length was discernable.

TABLE 3.

Food item occurrence (% total catch in which item present).

Food item	*Millbrook*	*Uraidla*
Cladocera		
Chydoridae *Alona* sp.	11	33
Leydigia sp.	15	—
Graptoleberis sp.	—	10
Chydorus sp.		14
Unidentified	26	14
Bosminidae *Bosmina* sp.	56	—
Macrothricidae *Macrothrix* sp.	4	5
Ephippium of *Daphnia* sp.	26	—
Copepoda		
Cyclopoida	48	10
Ostracoda		
Cyprididae *Candonocypris* sp.	30	
Rotifera		
Lecanidae		19
Trichoptera		
Leptoceridae	11	—
Empty cases	11	—
Ephemeroptera		
Caenidae	7	
Hemiptera		
Unidentified adult	4	4
Diptera		
Chironomidae larvae	44	19
pupa	7	5
Mollusca		
Pelecypoda *Sphaerium* sp.	7	—
Unidentified insect fragments	37	14
cladoceran fragments	41	10
ostracod fragments	30	100
mollusc fragments	11	100
Chlorophyta		
Ankistrodesmus sp.	—	52
Scenedesmus sp.	-	71
Pediastrum sp.	—	67
Staurastrum sp.	—	67
Unidentified filamentous alga	—	81
Chrysophyta		
Meridion sp.		90
Gomphonema sp.	—	90
Cocconeis sp.	—	86
Cyclotella sp.	—	81
Cymbella sp.	—	81
Closterium sp.	—	71
Navicula sp.	—	57
Diploneis sp.	—	71
Fragilaria sp.	—	90
Amphora sp.	—	62
Stauroneis sp.	—	67
Unidentified plant material	37	—
Detritus	93	100

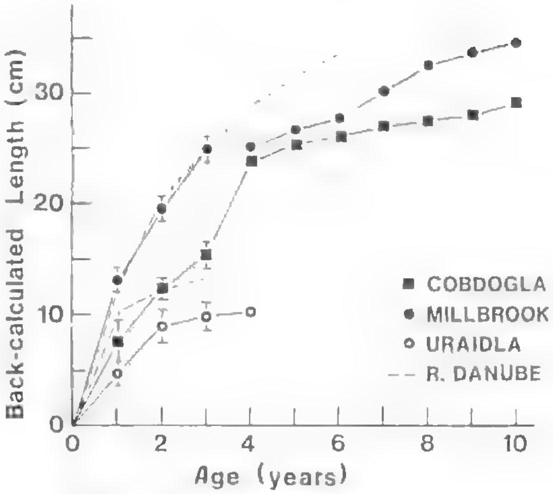

Fig. 4. Growth of *Carassius auratus*.

Food items found in the intestines of fish from Millbrook and Uraidla together with percentage occurrence in each locality are presented in Table 3. A wide variety of organisms were present including cladocerans, copepods, ostracods, rotifers, caddisflies, mayflies, chironomids, molluscs, green algae and diatoms. The genera of organisms present in intestines are all characteristically littoral in habit, usually associated with the sediments (Brooks 1959; Edmonson 1959; Wilson & Yeatman 1959; Chapman 1967; Williams 1968; Patrick 1977).

The mean % composition of the gut contents of fish from Millbrook and Uraidla, analysed by the points method, is presented in Figure 5. Differences in gut content between populations were apparent, principally involving diatoms, cladocerans and molluscs.

Discussion

Growth rate varied markedly between the populations of golden carp sampled. The factors responsible for growth differences may be temperature, food, or genetic variation in growth potential. The Cobdogla population would be expected to experience generally higher temperatures than the Millbrook and Uraidla populations (Bureau of Meteorology 1975). However, the Cobdogla population had only intermediate growth. No conclusion can be drawn from the data presented as to the relative effects of diet on growth. Fish have wide and variable food habits and preferences may vary seasonally and with age (Hynes 1950; Keast 1978).

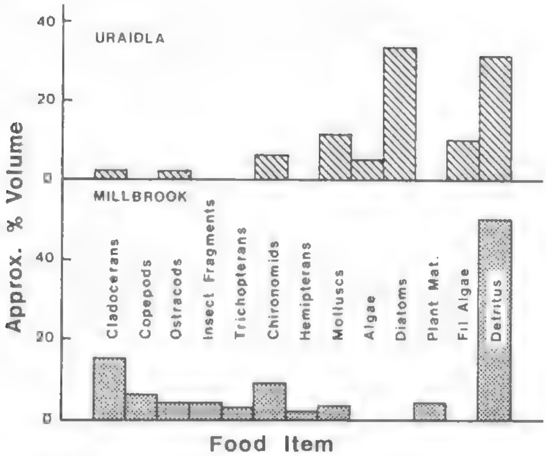

Fig. 5. Composition of gut contents (% estimated volume based on points method).

The influence of genetic variation on growth rates is usually masked by environmental factors but differences in growth do occur between forms of golden carp (Kukuradze & Mariyash 1975) and also of European carp (Lagler, Bardach, & Miller 1962).

Populations of golden carp in this study exhibited lower growth rates than mainland populations of other introduced cyprinids (tench, European carp) in Australia (Weatherley & Lake 1967; Jones[1]). In the River Murray, S.A., European carp may reach three times the length of golden carp from Cobdogla in their first year of growth.

Organisms found in fish from Millbrook and Uraidla were all characteristic of the littoral zone and usually associated with the sediments. This, and the high proportion of detritus in fish from both populations, suggests that fish were feeding near the bottom and ingesting sediments. The absence of diatoms from Millbrook fish may be the result of poor development of a benthic diatom community in that habitat or of fish feeding on benthos below the light extinction level.

Archibald (1975) has recorded size-selective predation by golden carp, 10–12 cm long, on species of *Daphnia* and fish from the Albury-Wodonga area appear to feed on microcrustacea including true planktonic forms (Walker & Hillman 1977). Whereas fry of this species may feed on zooplankton, adult fish are usually more omnivorous (Lake 1966).

Tench have a "wide ranging carnivorous" diet (Weatherley & Lake 1967) with insects becoming more important in larger fish. However, bottom dwelling organisms occur in fish from some habitats (Weatherley 1959). Golden carp from Millbrook and Uraidla appear to feed in a more strictly iliophagic manner than tench. The food requirements of the two species appear to overlap to some extent, although the intensity of competitive interactions will probably vary between localities.

The European carp is described generally as a 'bottom feeding omnivore' (Weatherley & Lake 1967) although diet appears to vary widely between populations (McCrimmon 1968). Although the golden carp is capable of increasing water turbidity (Lake 1966) it is generally assumed not to feed in the same manner as the European carp. The latter typically "suck up mud and other materials from the bottom, eject it, and select food when it is suspended in the water" (McCrimmon 1968). The gill rakers of this species are short, thick, and widely spaced (Kazansky 1964) suggesting that fairly large objects are dealt with (Nikolsky 1963). The gill rakers of golden carp are longer and more slender with lateral processes (Iwata 1976) accounting for the ability of this species to feed on plankton. Golden carp may "skim off" the top layer of the sediments, filtering out diatoms and microcrustacea, or simply ingesting all the material. European and golden carp may compete more directly than is the case for tench.

Neither European nor golden carp possess a true stomach (Suyehiro 1942; Shuljak 1968). The digestive tract of the golden carp appears to be relatively longer than that of the European carp by a factor of two or three (Suyehiro 1942) suggesting that golden carp has characteristically more indigestible material in its diet (Nikolsky 1963; Kapoor, Smit, & Verighina 1975). However, in Australia the European carp has been viewed as the major detritivore amongst the introduced cyprinids. This study has shown that golden carp may be iliophagic in some localities.

The precise nature of diet, gut morphology, and mode of feeding needs to be determined for golden and European carp in Australia. The question of the relative effects of each species on water turbidity, and therefore other aquatic organisms, is important as they appear to be most abundant in similar habitats and may hybridize (McCrimmon 1968). The study of wild populations of golden carp is important, both intrinsically and within the wider context of delimiting the effects of introduced fishes on the Australian aquatic environment.

Acknowledgments

I would like to thank Dr K. Walker for invaluable assistance in data analysis, P. De Deckker, R. Shiel, and Dr J. Bishop who helped with identifications; R. Croome for assistance at Millbrook; Mr and Mrs Richardson for use of their dam. This work was undertaken during the course of research for a Ph.D. under the supervision of Prof. W. D. Williams, and was supported by a Commonwealth Postgraduate Research Award.

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THE MOSSGIEL METEORITE

M. J. FITZGERALD

Summary

The Mossgiel meteorite, found in southwestern New South Wales in 1967, is described briefly. Its chemistry and mineralogy are consistent with its classification as an LL4 chondrite.

THE MOSSGIEL METEORITE

M. J. FITZGERALD*

Summary

FITZGERALD, M. J. (1979) The Mossgiel Meteorite. *Trans. R. Soc. Aust.* **103**(6), 145-147, 31 August, 1979.

The Mossgiel meteorite, found in southwestern New South Wales in 1967, is described briefly. Its chemistry and mineralogy are consistent with its classification as an LL4 chondrite.

Introduction

The Mossgiel meteorite was found in 1967 by H. Watkin during harvesting in a wheatfield on his property "Killara", in southwestern New South Wales. As it had not been seen the previous year when the crop was sown, the meteorite may have been uncovered subsequently by wind erosion. The weathered condition of the meteorite indicates that it is not a recent fall.

A specimen of the find was identified as a meteorite by K. D. Collerson, at the Mining Museum, Sydney. Collerson subsequently acquired it, then in 23 pieces. He named it Mossgiel as it had been found southeast of that town (approximate site of find: 33°19'S, 144°47'E). Collerson registered the meteorite with the International Meteoritical Commission in 1969. The bulk of the meteorite is now in Canada where it was taken by him in 1972.

The meteorite was originally described as an olivine bronzite chondrite (Krinov 1970). However, results obtained by Mason (1974) and Fitzgerald (1979a) suggest a different classification. Here I present a brief description of the meteorite, bulk and mineralogical compositional data and discuss its classification.

Experimental methods

X-ray fluorescence analysis was used for the determination of all elements except sodium for which a flame photometric method was employed. A modified version of the Norrish & Hutton (1969) technique for X.R.F. analysis was used. Olivine determinations were carried out using the method of Yoder & Sahama (1957) which involves measurement of d_{130} spacings using zinc oxide as an internal standard. Details of methods are in Fitzgerald (1979a).

Description of the meteorite

A small fragment of the meteorite was examined. Isolated grains of metal and tarnished sulfides are disseminated throughout the silicates which are stained brown from oxidative alteration. In places these iron-rich opaque minerals have been completely replaced with limonite and other oxides. Chondrules are visible on a cut surface, many being partly or wholly surrounded by troilite rims; they can also be seen penetrating through the fusion crust.

The major minerals present in the meteorite are olivine, pyroxene and metallic nickel-iron. Minor amounts of troilite and other minerals are present. The composition of the olivine as determined by X-ray diffraction, $Fa_{28.6}$, compares well with the value of $Fa_{29.2}$ reported for this meteorite by Mason (1974) using an electron microprobe. The tendency to lower iron content in the diffraction results matches the trend observed for other meteorites by Mason (1974) and Fitzgerald (1979a).

In thin section the meteorite has a fragmental appearance, most of the silicates being heavily stained with limonite and other iron oxides. Chondrules are present in addition to lithic fragments and monomineralic grains. Many of the lithic clasts are fragments of porphyritic material containing clasts of skeletal olivine and polysynthetically twinned clinopyroxene. The latter commonly poikilitically encloses sub-rounded to rounded chadacrysts

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TABLE 1

Bulk chemical compositions and normative mineralogies

	Mossgiel	Oberon Bay	Lake Labyrinth	Ngawi
Elemental abundances (wt %)				
Fe	18.38	18.43	19.70	19.03
Mn	0.26	0.28	0.31	0.26
Ti	0.088	0.081	0.073	0.064
Ca	1.14	1.30	1.41	1.33
K	0.050	0.126	0.103	0.077
P	0.061	0.084	0.157	0.079*
Si	18.83	19.23	19.37	18.88
Al	1.27	1.17	1.42	1.17
Mg	15.44	15.00	16.03	15.34
Ni	1.15	1.28	1.20	1.06*
S	1.93	2.15	2.00	2.22*
Cr	0.29	0.31	0.31	0.42*
Na	0.55	0.71	0.86	0.73*
*Data from Mason & Wiik 1966.				
Atomic ratios (%)				
Ca/Mg	4.5	5.3	5.3	5.3
Fe/(Fe+Mg)	34	35	35	35
Al/Si	7.0	6.3	7.6	6.5
Ca/Si	4.3	4.7	5.1	4.9
Fe/Si	49	49	51	51
Normative mineralogy (wt %)				
Nickel-iron	9.4	10.5	9.3	8.6
Troilite	5.5	6.2	5.5	6.3
Merrillite	0.3	0.4	0.8	0.4
Ilmenite	0.3	0.3	0.2	0.2
Chromite	0.7	0.7	0.7	0.9
Feldspar	10.1	10.7	12.2	10.5
Diopside	3.4	5.5	4.7	6.2
Orthopyroxene	37.2	38.4	25.4	30.4
Olivine	33.1	27.4	41.2	36.6
Molar % composition				
Ab	65.8	79.9	80.9	82.4
An	30.7	11.8	13.4	12.5
Fs	15.3	13.4	15.9	16.0
Fa	18.0	15.8	18.7	18.8

of olivine or orthopyroxene. A significant number of poikilitic orthopyroxene grains are present also. In many cases the brecciated nature of the meteorite is partially obscured by an integration of clast margins, possibly produced by recrystallization. Many of the chrondrules are fractured, and now have veins of opaque minerals running between the fragments. Much of the glassy mesostasis in the porphyritic inclusions has been devitrified to fine grained pyroxenes, while in some cases, some clasts appear to have been completely devitrified and recrystallized. Evidence of shock, in the form of undulose extinction, can be seen in many of the larger pyroxene grains and in many instances a mosaic texture is present. In contrast, most of the olivine grains are characterized by sharp extinctions.

Bulk chemical composition

The bulk composition is listed in Table 1 along with the results of a normative calculation. The assumptions made in this modified form of the CIPW calculation are documented fully by Fitzgerald (1979a). Phosphorous has been assigned to the mineral species merrillite (β-$Ca_3(PO_4)_2$) as this has been shown by Dowty (1977) to be the principal meteoritic phosphate.

Classification

Values of the atomic ratios (expressed on a percentage basis) Ca/Mg (4.5), Fe/(Fe + Mg) (34), Al/Si (7.0) and Ca/Si (4.3) all fall within the ranges used by Fitzgerald (1979a) to define the ordinary chondrites. Both the absolute iron content (18.4%) and the low value of 49 for the Fe/Si ratio are suggestive of an LL chondrite classification whereas the olivine composition of approximately Fa_{24} is appropriate to the L group. Mossgiel belongs to petrologic type 4 (Mason 1974) and so it is possible that it contains unequilibrated silicates. Electron microprobe determinations were not carried out on this meteorite and so this point could not be confirmed. Dodd *et al.* (1967) found that in the L and LL chondrites the average iron content of the olivine increases during equilibration. As a result, unequilibrated members of these groups can have olivine compositions appropriate to the H or L groups, but bulk chemistries characteristic of either the L or LL group. (It is also possible that the fairly extensive weathering, seen in thin section, has resulted in an iron-loss, with the result that the olivine composition accurately indicates the correct classification.)

Mason & Wiik (1964) suggested that the LL chondrites are frequently characterized by a scarcity of chondrules and a prominent brecciation. The texture of Mossgiel does not completely accord with this description, but since nine of the 12 meteorites examined by these authors belonged to the LL6 group, the lack of chondrules probably only reflects recrystallization effects, and is not necessarily typical of the LL group as a whole. Fodor & Keil (1975) also pointed out that the LL

chondrites are characterized by their brecciated structure and described poikilitic lithic fragments from five LL chrondites. In general, they found olivine chadacrysts poikilitically enclosed in orthopyroxene oikocrysts.

Comparison of Mossgiel with a section of the LL5 chondrite Forrest Lakes, figured by McCall & De Laeter (1965), shows some points of similarity. Lake Labyrinth, an LL6 chondrite, has been more extensively recrystallized than either Mossgiel or Forrest Lakes, with the result that very few chondules can be seen. This recrystallization has not, however, destroyed the poikilitic nature of the large orthopyroxene grains which enclose chadacrysts of olivine. Both Forrest Lakes and Lake Labyrinth were found in the Nullarbor Plain, Forrest Lakes just west of the state border and Lake Labyrinth northwest of Kingoonya. The fall of the latter (recovered in 1934) was probably witnessed in 1924. A complete analysis of this meteorite has not been published previously. Accordingly, an analysis obtained using the same analytical technique is included in Table 1, as is one of Oberon Bay, another LL chondrite examined in this work. This latter meteorite, which was recovered on Wilson's Promontory, has some unusual features and is described in full by Fitzgerald (1979b). Table 1 also includes analytical results for the LL3 chondrite Ngawi. Much of these data were obtained by Ahrens *et al.* (1969) using a similar X.R.F. method of analysis. In order to present a complete analysis, these results were supplemented by those of Mason & Wiik (1966).

On the basis of textural relationships and its bulk chemistry Mossgiel is classified as an LL4 chondrite. The apparently olivine composition may be the result of lack of equilibrium in the major silicate minerals.

Acknowledgments

This work was carried out during the tenure of a University of Adelaide Postgraduate Research Grant. Receipt of this is gratefully acknowledged as is the help and constructive criticism of Dr J. B. Jones.

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A NEW SPECIES OF CAVE-DWELLING, HYLID FROG FROM MITCHELL PLATEAU, WESTERN AUSTRALIA

BY MICHAEL J. TYLER AND MARGARET DAVIES

Summary

A new species of Litoria is described. It is of moderate size (males 44-51 mm; females 50-57 mm S-V), and is a further representative of the L. caerulea group. Amomgst its osteological features it is unique in Litoria in exhibiting a supraorbital sphenethmoid flange.

A NEW SPECIES OF CAVE-DWELLING, HYLID FROG FROM MITCHELL PLATEAU, WESTERN AUSTRALIA

by MICHAEL J. TYLER* AND MARGARET DAVIES*

Summary

TYLER, M. J. & DAVIES, M. (1979) A new species of cave-dwelling, hylid frog from Mitchell Plateau, Western Australia. *Trans. R. Soc. S. Aust.* 103(6), 149-153, 31 August, 1979.

A new species of *Litoria* is described. It is of moderate size (males 44-51 mm; females 50-57 mm S-V), and is a further representative of the *L. caerulea* group. Amongst its osteological features it is unique in *Litoria* in exhibiting a supraorbital sphenethmoid flange.

Introduction

For over a century *Litoria caerulea* (Shaw) was considered a highly distinctive hylid frog, and in fact Gunther (1858) erected the genus *Pelodryas* and family Pelodryadidae to accommodate it. The species was first reported from South Australia by Tyler (1977). Tyler *et al.* (1977) described the new species *Litoria splendida* which they considered derived from it, and Tyler and Davies (1978) associated the two species within a species group.

This paper describes a further new species of the *L. caerulea* species group.

Materials and Methods

The specimens reported here are deposited in museums abbreviated as follows: KU Museum of Natural History, University of Kansas; SAM — South Australian Museum; WAM — Western Australian Museum.

Methods of measurement follow those of Tyler (1968), whilst the abbreviations used in referring to various features employed in morphometric investigations are: E-N eye to naris distance; HL head length; HW head width; IN internarial span; S-V snout to vent length; TL tibia length.

The format of the osteological descriptions follows Trueb (1979).

Litoria cavernicola new species

Holotype

WAM R43228. An adult male collected approximately 3 km west of Surveyors Pool, Mitchell Plateau, Kimberley Division, Western Australia, on 17 February, 1973 by L. A. Smith and R. E. Johnstone.

Definition

The characteristic features of this species are its moderate size (males 44-51 mm; females 50-57 mm S-V length); long and slightly webbed fingers with large discs, partially webbed toes, large distinct tympanum and coarsely granular skin. The animal is a dull green or greenish brown in life.

Description of holotype

Head slightly broader than long (HL/HW 0.92), its length equivalent to one-third of the snout to vent length (HL/S-V 0.35). Snout prominent, truncated when viewed from above and in profile. Nostrils more lateral than superior; their distance from end of snout considerably less than that from eye. Distance between eye and naris greater than internarial span (E-N/IN 1.20). Canthus rostralis moderately defined and straight. Eye large and prominent, its diameter greater than eye to naris distance. Tympanum large and entirely visible, its diameter four-fifths of eye diameter (Fig. 1).

Vomerine teeth extremely prominent, on greatly elevated series almost entirely posterior to choanae. Tongue broad.

Fingers long and with scarcely detectable lateral fringes; in decreasing order of length 3 > 4 > 2 > 1. Webbing between fingers only basal. Terminal discs broad, oval and truncated distally (Fig. 2). Subarticular tubercles very large and prominent.

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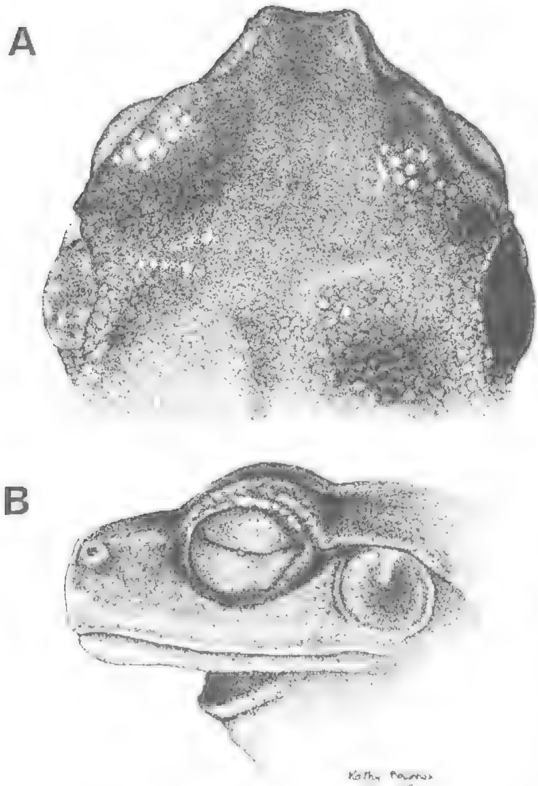

Fig. 1. (A) dorsal and (B) lateral views of the head of *Litoria cavernicola*. Paratype WAM R44328.

Hind limbs rather short (TL/S-V 0.48). Toes in decreasing order of length 4 > 5 > 3 > 2 > 1. Webbing on toe 5 reaches slightly above subarticular tubercle at base of penultimate phalanx; extends to subarticular tubercle at base of penultimate phalanx of toe 4 and continues to discs in form of broad lateral fringe. Subarticular tubercles prominent. Large oval inner and small rounded outer metatarsal tubercles (Fig. 2).

Dorsum coarsely granular; skin fold along posterior edge of forearm and slight tarsal fold. Supratympanic fold narrow. Ventral surface coarsely granular.

In preservative the dorsum is a uniform pale brown and the ventral surface uniform pale cream.

This male specimen has unpigmented nuptial pads, and a submandibular vocal sac with short apertures near the articulation of the jaws.

Dimensions of holotype

Snout to vent length 48.0 mm; head length 16.7 mm; head width 18.2 mm; tibia length 23.0 mm; eye to naris distance 4.8 mm; internarial span 4.0 mm; eye diameter 5.3 mm; tympanum diameter 4.2 mm.

Variation

There are 14 paratypes: WAM R43329-30 collected with the holotype by L. A. Smith and R. E. Johnstone; WAM R60680-84 collected at East Mitchell Falls, by W. H. Butler on 4.11.78; WAM R61624-30 sandstone upon Mitchell Plateau, W. H. Butler 20-28.2.79. Five of the paratypes are adult males (44-50 mm S-V) and two are females (50 and 57 mm S-V respectively). The larger of the females is gravid; the smaller has few ova but convoluted oviducts and may have deposited ova shortly before capture.

The overall proportions of the paratypes are similar (HL/HW 0.89-1.05; HL/S-V 0.32-0.37; E-N/IN 1.13-1.38). The tympanum is clearly defined and a distinctive feature in all representatives. Webbing shows no detectable variation. The skin is coarsely granular in the series collected at Surveyors Pool, but less conspicuously granular in the series from the East Mitchell Falls.

Osteology (based on WAM R60681—Fig. 3)

Skull moderately well ossified, broader than long; sphenethmoid well ossified projecting between nasals almost to anterior extremities. Ventrally ossified portion of sphenethmoid extends between the prevomers to the level of their anterior extremities. Supraorbital sphenethmoid flanges present laterally, abutting with anterior extremities of frontoparietals. Prootic and exoccipital bones fused completely. Crista parotica narrow, moderately short, widely separated from otic ramus of squamosal; epio-

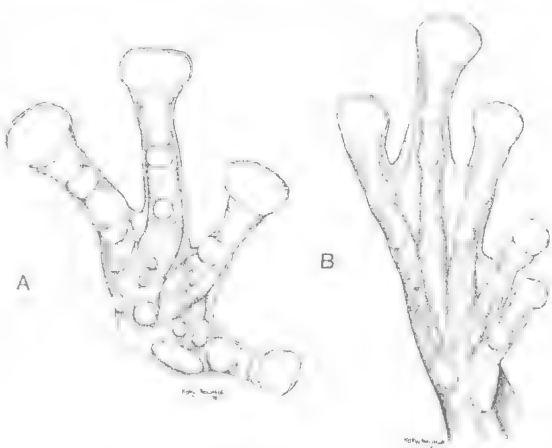

Fig. 2. (A) hand and (B) foot of *Litoria cavernicola*. Paratype WAM R44328.

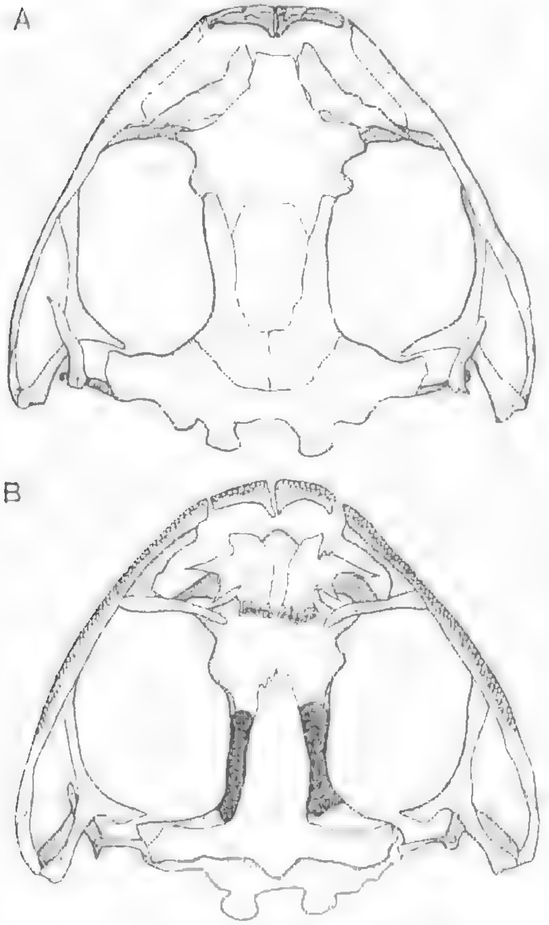

Fig. 3. (A) dorsal and (B) ventral view of the skull of *Litoria cavernicola*.

tic eminences prominent. Frontoparietal fontanelle moderately large, ovoid, anterior margin at level approximately 1/3 anteriorly on length of orbit, posterior margin 7/8 posterior on length of orbit. Lateral margins of frontoparietals straight. Frontoparietals not expanded posterolaterally to overlap crista parotica.

Nasals slender, widely separated medially, arched laterally, articulating with sphenethmoid anteromedially. Maxillary process of nasal slender, does not articulate with short preorbital process of moderately deep pars facialis of maxillary. Palatines moderately long, slender, ridged slightly, curved posteromedially, lying on bony sphenethmoid, laterally lying alongside maxillaries. Parasphenoid robust with short, broad, irregularly truncate cultriform process terminating approximately 1/3 anteriorly along length of orbit; alae long, narrow, at right angles to cultriform process, not overlapped laterally by short, robust medial arm of pterygoid.

Pterygoid moderately well developed, medial arm not in bony contact with prootic region, anterior arm articulating with maxillary at level approximately 1/3 anteriorly along length of orbit. Quadratojugal well developed, robust, firmly articulating with maxillary anteriorly and shaft of squamosal posteriorly. Squamosal moderately robust, otic plate absent, zygomatic ramus moderately well developed, slightly longer otic ramus. Maxillary and premaxillary dentate. Alary processes of premaxillaries moderately separated medially and perpendicular to the dentigerous processes. Palatine processes of premaxillaries well developed, do not quite meet medially. Shallow palatal shelf with no pterygoid process.

Prevomers entire, anterior alae reduced, lateral alae forming margins of choanae. Dentigerous proceses robust, moderately short and horizontal to the midline bearing seven teeth. Bony columella present.

Arciferal pectoral girdle robust. Omosternum and xiphisternum present. Sternum cartilaginous, well developed. Clavicles slender, arched, closely juxtaposed medially. Coracoids well developed, widely separated medially. Scapula bicapitate, slightly longer than clavicle. Supracapula 2/3 ossified.

Eight procoelous nonimbricate presacral vertebrae. Widths of transverse processes III = SD > IV > VI > II = VII = VIII > V. Sacral diapophyses moderately expanded, ilia project to their anterior extremeities. Urostyle bicondylar bearing a dorsal crest extending for

TABLE 1.

Comparison of size and proportions of L. caerulea *and* L. cavernicola *sp. nov. from the Mitchell Plateau.*

		S-V					
	n	♂♂	♀♀	E-N/IN	HL/HW	HL/S-V	TL/S-V
L. caerulea	13	67–77	72	0.89–1.08	0.86–0.96	0.29–0.32	0.39–0.44
L. cavernicola	8	44–50	50–57	1.13–1.38	0.89–1.05	0.32–0.36	0.42–0.50

about 3/4 of its length. Vestigial transverse processes absent.

Humerus bearing moderate anteroproximal crest. Phalangeal formula of hand 2-2-3-3; distal tips of phalangeal element clawed; intercalary structures very short and cartilaginous; bony prepollex present. Phalangeal formula of foot 2-2-3-4-3; vestigial bony prehallux present.

Comment: The presence of a supraorbital sphenethmoid flange has not been reported previously in the Hylidae. Supraorbital frontoparietal flanges are not uncommon, but the anterior progression of the flange is unusual.

Comparison with other species

The overall habitus of *L. cavernicola,* size of digital discs, presence of interdigital webbing and colour in life are all reminiscent of *L. caerulea,* and the relationship with that species appears closer than with any other congener. Accordingly it has been compared with individuals of *caerulea* from various parts of that species' range and a detailed morphometric comparison made with a series of 13 *L. caerulea* taken upon the Mitchell Plateau: KU 180663-64, SAM R17147-R17155. Table 1 demonstrates that *L. cavernicola* is significantly smaller, has more narrowly spaced nostrils (so producing a higher E-N/IN ratio), lacks the short head of *L. caerulea* (HL/S-V 0.32-0.37, compared with 0.29-0.32 in *L. caerulea*). *Litoria cavernicola* has longer legs; only one specimen having a TL/S-V ratio below the maximum for *L. caerulea.*

Litoria cavernicola lacks the large parotoid glands of *L. caerulea,* which in that species obscure the upper and posterior margins of the tympanum. Thus in *L. cavernicola* the tympanic annulus is entirely visible.

Features of the skull of *L. cavernicola* have much in common with *L. caerulea.* However some quite considerable differences have been observed as follows: nasals of *L. cavernicola* are more slender than those of *L. caerulea* whilst the sphenethmoid is more ossified in the former species. A supraorbital sphenethmoid flange is present in *L. cavernicola* compared with a small supraorbital frontoparietal flange in *L. caerulea.* The zygomatic ramus of the squamosal is shorter and otic ramus longer in *L. cavernicola* than *L. caerulea.* The preorbital process of the pars facialis is in bony contact with the maxillary process of the nasal in *L. caerulea* but not in *L. cavernicola.* The alary processes of the premaxillaries are perpendicular in *L. cavernicola* and curved posteriorly in *L. caerulea.* The anterior alae of the prevomers are reduced in *L. cavernicola* but not in *L. caerulea.* The cultriform process of the parasphenoid is irregularly truncate in *L. cavernicola* but acuminate in *L. caerulea* whilst the alae are at right angles to the cultriform process in *L. cavernicola* but directed slightly posterolaterally in *L. caerulea.*

Relative widths of the transverse process of the presacral vertebrae differ, being III = SD > IV > VII > II = VII = VIII > V in *L. cavernicola* and III = SD > IV > V = VI = VII = VIII > II in *L. caerulea.*

Litoria splendida is a further representative of the *L. caerula* species group as defined by Tyler and Davies (1978). It is a large species (up to 100 mm S-V) and is distinguished from *L. cavernicola* by possession of vast, hypertrophied, supracranial glands and conspicuous pale yellow spots upon the green dorsum.

Habitat

Litoria cavernicola has been collected only from large caves in sandstone gorges. Elsewhere in the Kimberleys such caves are inhabited by *L. caerulea* and *L. splendida.*

Distribution

Only known from the gorges bordering the Mitchell Plateau, W.A., but possibly widespread in comparable gorges in the inaccessible country (subhumid northwest Kimberley).

Etymology

The specific name is derived from the Latin *caverna* (a hollow; cave or cavern) and *cola* (inhabitant).

Acknowledgements

This study is supported by a grant from the Australian Research Grants Committee to M. J. Tyler. Field studies at the Mitchell Plateau were undertaken as part of the development of an environmental management programme by Amax (Australia) Pty Ltd.

We are indebted to Dr G. M. Storr of the Western Australian Museum for the opportunity to examine this material, and to Mr L. A. Smith and Mr R. E. Johnstone for their helpful advice. Figures 1 and 2 were prepared by Kathy Bowshall.

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OSTRACODS FROM THE MOUND SPRINGS AREA BETWEEN STRANGWAYS AND CUDIMURKA, SOUTH AUSTRALIA

BY P. DE DECKKER

Summary

Ngarawa dirga n.gen., n.sp. of the new subfamily Ngarawinae, is described from mound springs and spring seeps in the Strangways-Curdimurka area, southwest of Lake Eyre South. Two other cyprididid ostracods are recorded from temporary pools in the same area: Reticypris walbu n. sp. and Heterocypris tatei (Brady, 1886). The latter species is redescribed and recorded from some mound springs.

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Introduction

Natural artesian springs commonly occur along the edge of the Great Artesian Basin and some are in the area between Strangways and Curdimurka, South Australia. Some of these consist of dome-shaped structures or "mounds" (Fig. 1) from which water flows slowly. Inside the open domes, small pools often occur which overflow through a "seep" (Fig. 2). The waters from these springs are commonly slightly saline and alkaline having conductivities of up to 9000 millimhos/cm. Spring water temperatures are usually high (e.g. 18-30° in early October 1978), those of the seeps characteristically higher than the pools. As the mound springs are the only

Fig. 1. Mound at Horse Springs. Note the characteristic cone shape of the spring. The sides of the spring are made of calcareous encrustations leached by the spring waters. Distance across the top of the spring is approximately 20 m. (Photo B. D. Mitchell).

Fig. 2. Seep on mound at Horse Springs. This narrow and very shallow waterbody is covered at the bottom with encrusting algae on which the ostracod *Ngarawa dirga* n. gen., n. sp., and the isopod *Phreatomerus latipes* are crawling. The water depth is sometimes only a few millimetres. (Photo B. D. Mitchell).

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prominent water bodies in an arid area, they might be expected to provide unique habitats for an endemic fauna, as is the case for the remarkable phreatoicid isopod *Phreatomerus latipes* (Chilton, 1922). As yet undescribed gastropods collected from the same mound springs are also endemic (B. V. Smith *in litt.* to B. D. Mitchell, 24.xi.1978). One new ostracod genus and new species is a common inhabitant of the mound springs and their seeps, and believed to be endemic to the area. For further details of the area, refer to Cobb (1975) and Mitchell (in press).

The material analysed here was collected by B. D. Mitchell during the period of 30.ix.-3.x. 1978 during an investigation of the mound springs by the Nature Conservation Society of South Australia. Some collections made by K. F. Walker in the same area were also examined.

The specimens used for the description of the three ostracod species are deposited at the Australian Museum (AM P28669-P28692). Paratype material is also deposited at the South Australian Museum, British Museum (Natural History) and U.S. National Museum.

Aboriginal words are used here to name the new ostracods because the area where they were collected is rich in myths of the Arabunna people.

Systematic Descriptions

Subclass: OSTRACODA Latreille, 1806
Order: PODOCOPIDA Müller, 1894
Superfamily: CYPRIDACEA Baird, 1845
Family: CYPRIDIDAE Baird, 1845
Subfamily: NGARAWINAE new subfam.

Type genus: Ngarawa dirga n. gen., n. sp.

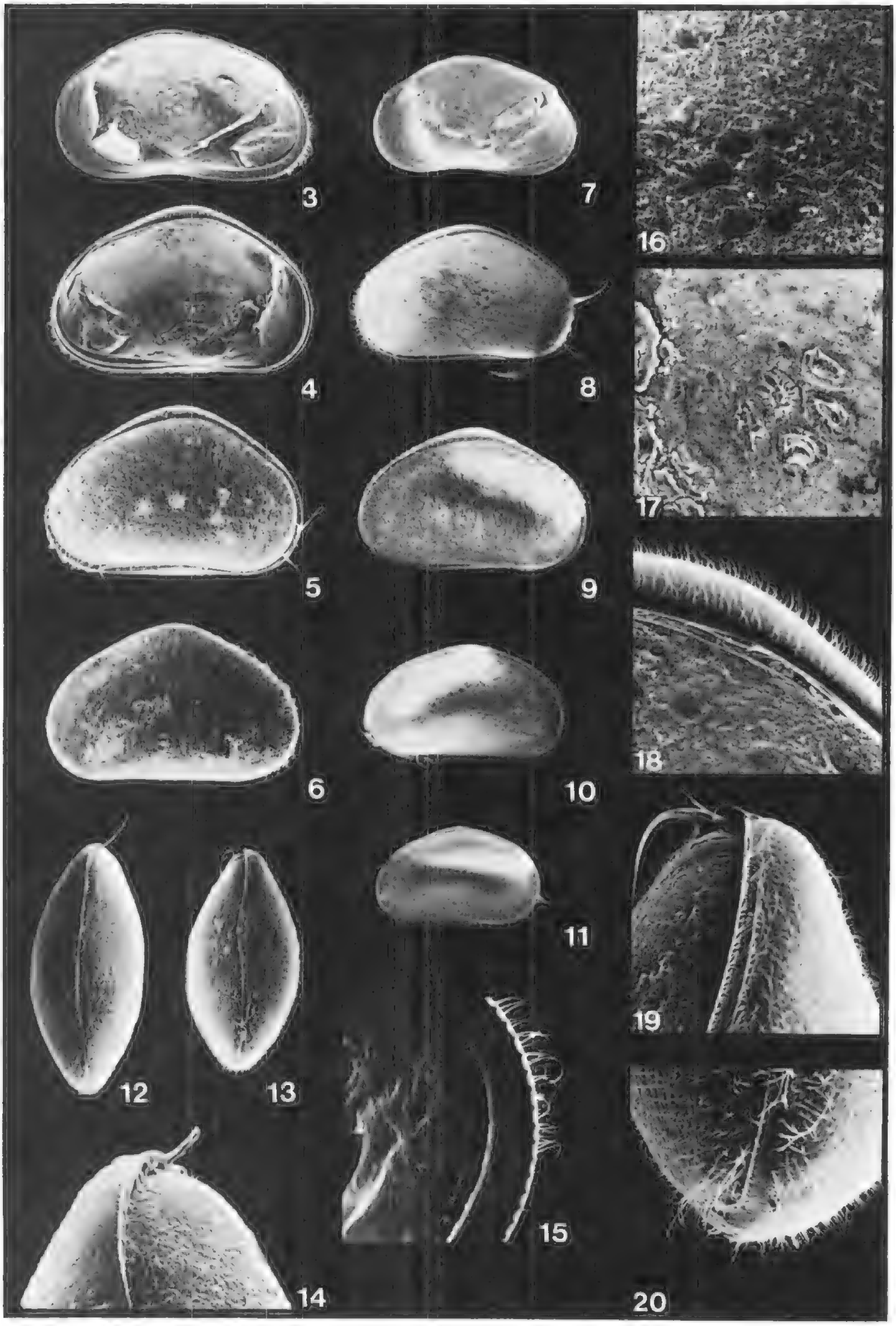
Diagnosis: Carapace: left valve with dorsal hump and slightly larger than right valve; edge of right valve with faint tuberculation posteriorly; broad selvage near edge of left valve but forming edge of right valve; calcified inner lamella broad anteriorly; central muscle scars consisting of 6 scars at the maximum arranged in circle; 2 on top with one or 2 below in centre, and 2 others below; 2 mandibular scars below and in front; radial pore canals numerous, straight and arranged in groups of 2 and sometimes bifid; 4 rows of seminal vesicles forming U-shape in posteroventral area and forming 2 loops, one clockwise in dorsal area around central muscle field, the other anticlockwise in posterodorsal area.

Anatomy: antennula 7 segmented with one thick and straight bristle at the end of last segment; antenna with small unequal natatory setae; mandibular endopod with α bristle long, narrow and with pilose distal end, β bristle with small and fine short hairs and γ bristle very long and with pilose tip; rake-like organ with 6 teeth; last segment of maxillular palp trapezoid; the 2 Zahnborsten on 3rd lobe of maxillula with teeth; male maxillary palps almost identical with 2 long and narrow bristles plus 6 pilose bristles on epipod; Zenker organ with both ends rounded and bearing 25 rosettes; furca with 2 long claws almost equal in length and 2 bristles; furcal attachment with one ventral extension near articular extremity, 2 small dorsal branches and a bifid ventral one; no spine on posterior of body.

Remarks: This new subfamily is at present monospecific. The Ngarawinae resembles the Cyprinotinae in dorsal hump in left valve and tuberculate edge of one valve, but differs from it by possessing a trapezoid end segment of maxillular palp, almost identical maxillar palps in males, different shaped hemipenis (in Cyprinotinae it usually has a boot shaped lateral lobe) and furcal attachment with 2 dorsal branches and a ventral process near articulary extremity.

The furcal attachment, which was shown by Rome (1969) to be an important feature for distinguishing various subfamilies within the Cypridacea, separates *Ngarawa* from *Prionocypris* Brady & Norman, 1896, redescribed by

Figs. 3-20. *Ngarawa dirga* n. gen., n. sp. Female paratypes. 3: internal lateral RV; 4: internal lateral LV; 5: external lateral of carapace showing mainly RV; 6: external lateral of carapace LV. Male holotype. 7: Internal lateral RV. Male paratypes. 8: external lateral of carapace RV; 9: external lateral of carapace RV; 10: external lateral of carapace RV. Juvenile. 11: lateral of carapace RV. Female paratypes. 12: dorsal of carapace; 13: ventral of carapace; 14: detail of Fig. 12, anterior area of carapace. Male holotype. 15: detail of Fig. 7, posterior area. Male paratype. 16: detail of Fig. 8, central muscle scars; note photo at an angle from original. Female paratype. 17: detail of Fig. 3, central muscle scars. Male holotype. 18: detail of Fig. 7, dorsal area. Female paratype. 19: detail of Fig. 13, anterior area of carapace; 20: detail of Fig. 13, anterior area of carapace.
LV, RV = left vale, right valve. Figs 3-13: approx. 30x; 14-20: approx. 150x.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Danielopol & McKenzie (1977), which, otherwise resembles the former genus in many anatomical details. However, the similarity of the furcal attachment of *Ngarawa* with those of the genera included with the Herpetocypridinae still does not necessitate the association of this genus with *Herpetocypris, Ilyodromus* and *Psychrodromus* because the furca, another distinguishing taxonomic feature at the subfamily level, has different types of bristles. Therefore the Ngarawinae could be a transition form between the Herpetocypridinae and the Cyprinotinae. Whether or not it is ancestral to these families is not yet known.

Ngarawa n. gen.

Type species: Ngarawa dirga n. sp., gender feminine.

Diagnosis: Same as for subfamily Ngarawinae.

Derivation of name: From guda ngarawa in Arabunna vocabulary meaning mound spring, the typical habitat of that ostracod (guda meaning water).

Ngarwa dirga n. sp.
Figs. 3-34.

Holotype: Adult male, AM P8680.

Paratype: Ovigerous female, AM P8677.

Type locality: Blanche Cup Spring (lat. 29° 27′ 08″ S; lon. 136° 51′ 04″ E).

Derivation of name: Dirga meaning literally "oven" in the Arabunna vocabulary for Blanche Cup Spring.

Description: Carapace (External). Holotype adult male: length LV 1.13 mm, RV 1.10 mm; height LV 0.74 mm, RV 0.66 mm. Paratype adult female: length LV 1.20 mm, RV 1.18 mm; height LV 0.74 mm, RV 0.66 mm. In lateral view triangular in shape with dorsal hump in LV; greatest height at almost middle in both sexes; LV overlapping RV all along its edge; in dorsal view carapace narrow, and strong dorsal overlap of LV anteriorly and posteriorly; very broad overlap of LV in ventrum area; dorsum strongly arched and ventrum almost flat; length height ratio smaller in female; surface of shell very hairy in adults, less pilose in juveniles; normal pore canals simple and funnel shaped.

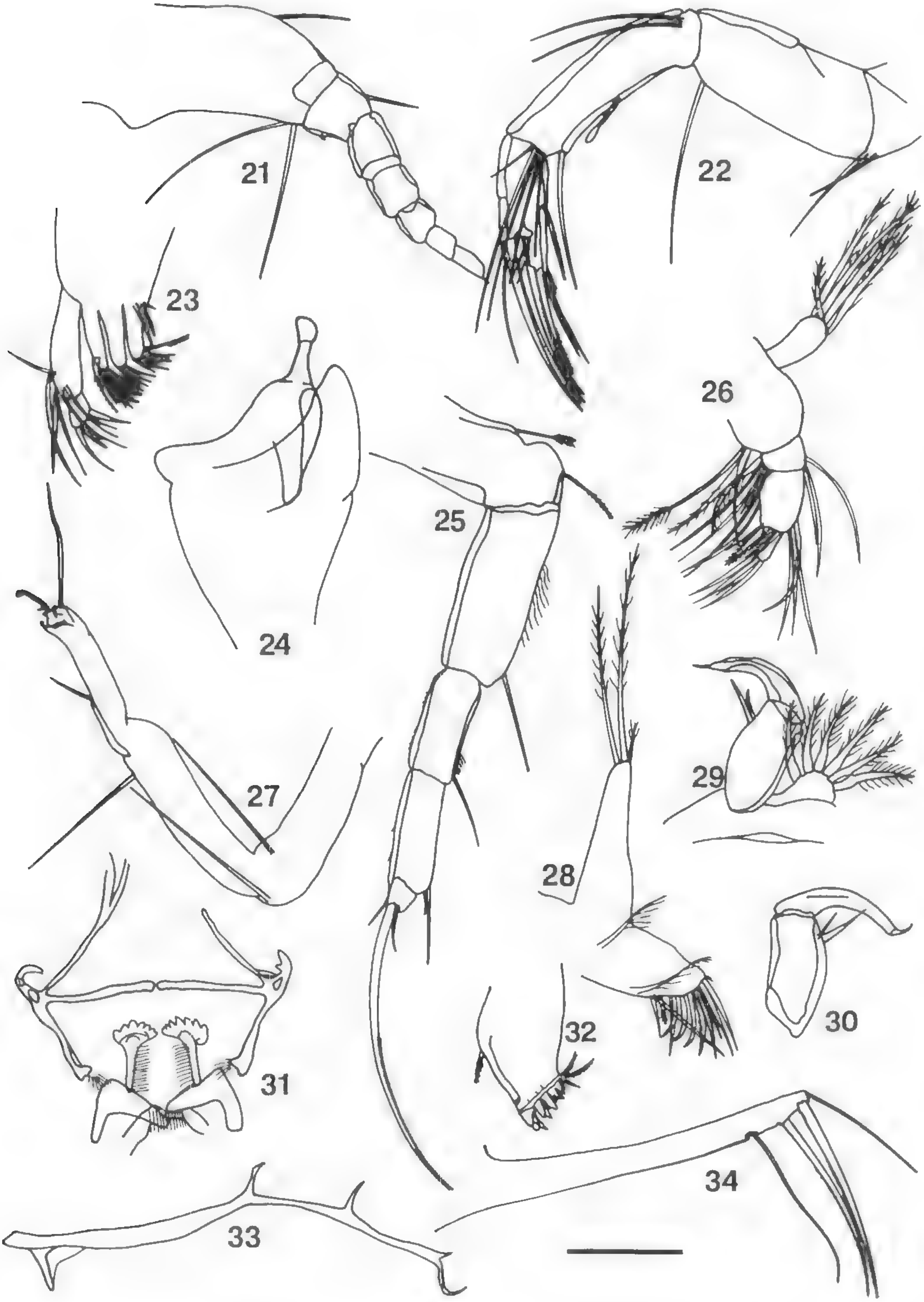
(Internal). Faint tuberculation (Fig. 15) on posterior edge of RV in both sexes; broad selvage near edge of valve in LV whereas it is forming the edge of RV; calcified inner lamella broad anteriorly in both valves and about 3 times its width posteriorly. Hinge: in LV fine groove below hump (Fig. 18) and ridge in RV which is interlocking below hump of LV. Central muscle scars (Figs 16-17) arranged in circle with 2 scars on top and one or 2 below in centre (posterior one placed higher) and 2 others below; 2 mandibular scars below and in front. Radial pore canals straight, arranged in groups of 2 and sometimes bifid in anterior area of LV. Seminal vesicles U-shaped posteroventrally and curling clockwise around and above central muscle field and anticlockwise in posterodorsal area.

Anatomy. Antennula: (Fig. 21); 7 segmented; length/width ratio of last 6 segments: $\frac{7}{8}, \frac{7}{7}, \frac{8}{6.5}, \frac{5}{5.5}, \frac{4.5}{3.5}, \frac{5}{2.5}$; last segment with thick and stiff bristle as long as last 5 segments and half length of other setae; sensory organ on 2nd segment small, transparent and rod-shaped.

Antenna: (Fig. 22); sexually dimorphic; sense club attached at mid length on 1st segment; natatory setae unequal and not reaching tips of claws; 4 claws: the one fixed to 3rd segment being shortest and longer in male. In female, a thick seta with long hairs protrudes from last segment.

Mandible: mandibular coxale (Fig. 32) with last molar slender and longer than last 3; near its base: 2 pilose short bristles; endopod (Fig. 26) with α bristle long, narrow and with few distal spines, β bristle small and with fine, short hairs and γ bristle with fine hairs at distal end, as long as setae with double row of spines (for terminology see Danielopol & McKenzie 1977) and near the latter ones, presence of a small bristle; epipod plate with 5 plumose Strahlen.

Figs. 21-34. *Ngarawa dirga* n. gen., n. sp. Male holotype. 21: antennula (segments only); 22: antenna; 23: maxillular palp with lobes; 24: hemipenis; 25: thoracopoda I; 26: mandibular endopod; 27: thoracopoda II. Female paratype. 28: maxilla. Male holotype. 29: maxilla, detail of palp; 30: maxilla, detail of other palp. Female paratype. 31: detail of lower lip in mouth area including rake-like organs; 32: detail of mandibular coxale. Male holotype. 33: furcal attachment; 34: furca.
Scale: 100μ.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Rake-like organ: (Fig. 31); 6 teeth with inner one bifid; teeth decreasing in size and width towards inside.

Maxillula: (Fig. 23); length/width ratio of palp segments: $\frac{15}{4.5}$, $\frac{3.5}{4}$; last segment trapezoid and with 3 thick bristles; 3rd lobe with 2 Zahnborsten: 3-4 teeth on anterior Zahnborste of male, 6-3 in female and 4-2 on posterior Zahnborste in both sexes.

Maxilla: sexually dimorphic: in male, prehensile palps (Figs 29-30) almost identical and with 2 long bristles; epipod with 6 plumose Strahlen; in female (Fig. 28) endopod with 3 unequal plumose setae: the middle one being the longest and 6 times as long as small one and $\frac{5}{4}$ the other; protopod with 12 terminal bristles, one subterminal one and another near base of endopod.

Thoracopoda I: penultimate segment divided; terminal claw longer than last 2 segments; for detail of setae, see Fig. 25.

Thoracopoda II: terminal segment with one pincer and 2 unequal setae, the smallest hook-shaped and bearing small teeth; for details of setae see Fig. 27.

Hemipenis: for outline refer to Fig. 24.

Zenker organ: bearing 25 rosettes and both ends rounded.

Furca: (Fig. 34); 2 long claws and 2 long bristles; anterior claw slightly longer than posterior and almost 2/3 length of shaft; both claws pectinate along 2/3 of length down to tip; anterior bristle, flagellum like, almost same length as posterior claw; distance along shaft between posterior bristle and claw; 1/11 of length of shaft.

Furcal attachment: (Fig. 33); one ventral extension near articular extremity (= terminology of Rome 1969) which is almost perpendicular to median part; two small dorsal branches, almost as long as ventral extension, one at mid-length and other at 3/4 length from articular extremity; ventral branch bifid with lower part longer and hook-shaped.

Posterior end of body: smooth, no spine.

Eye: cups of nauplius eye fused; colour: brown.

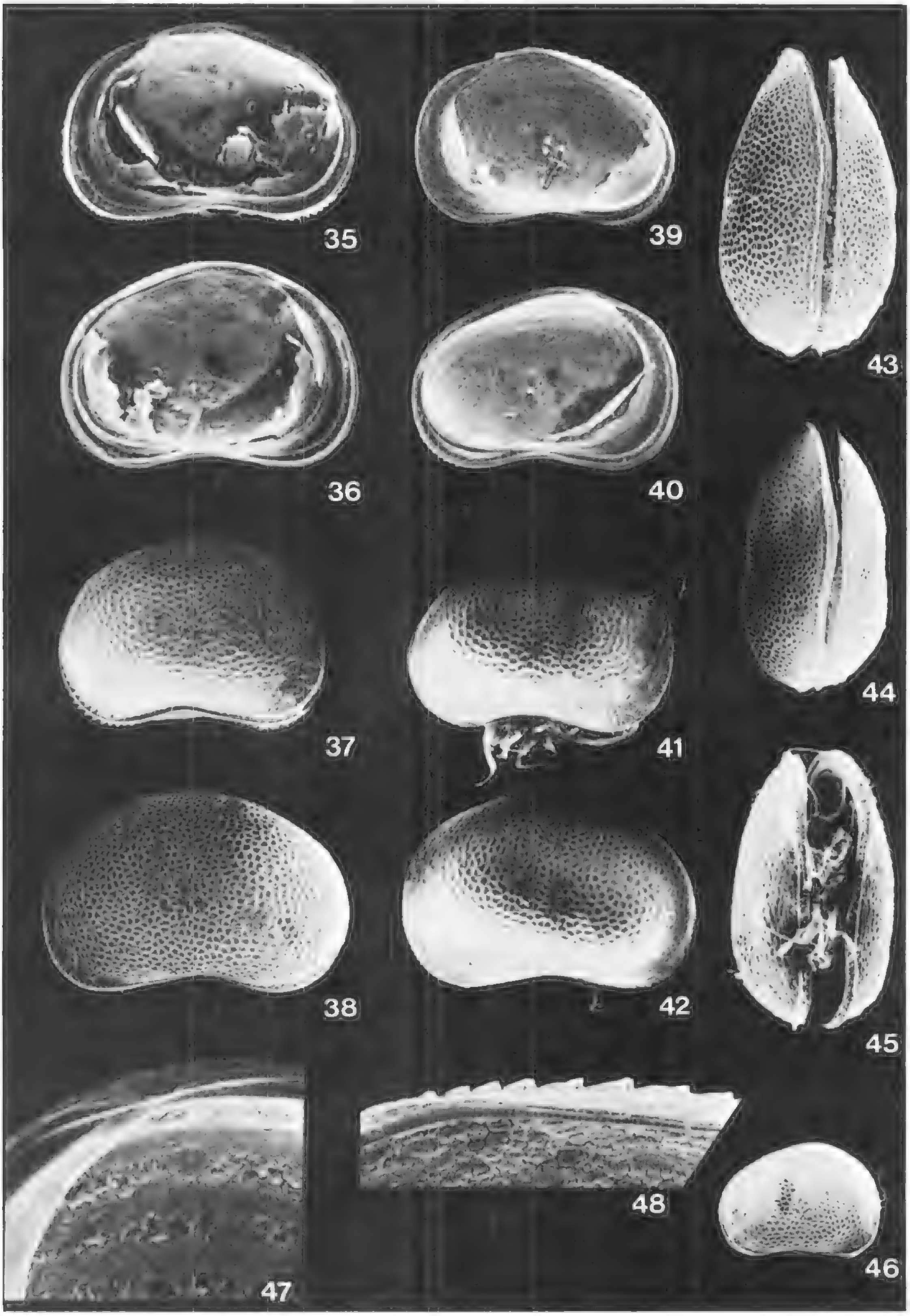
Colour of valves: light green (in type locality) to brown-orange (e.g. the Bubbler).

Ecology: Ngarawa dirga is a benthic ostracod found in most springs in the Strangways-Curdimurka area. B. D. Mitchell collected specimens of this species from the following: Hamilton Hill Homestead Spring (T. 18°C, cond. 8970 mmho); unnamed spring near Blanche Cup; Blanche Cup (T. 14°C, cond. 6952 mmho); The Bubbler (T. 30°C, cond. 5943 mmho); Coward Spring Railway Bore—swamp; Coward Springs (T. 28°C, cond. 6811 mmho); Warburton Spring; Strangways Spring. *N. dirga* was also collected from 2 mound springs seeps: Horse Springs Seep (T. 23°C, cond. 7047 mmho) and Blanche Cup seep (T. 28°C). K. F. Walker collected *N. dirga* on 30.xi.1975 from the Blanche Cup Spring (T. 29°C), the Bubbler (T. 31°C) and the Little Bubbler (T. 28.5°) near the latter spring. For all these localities refer to the 1:250 000 Curdimurka topographic map.

Mitchell noticed that in the seeps, *N. dirga* was crawling on a rocky bottom covered with algae and also within sandy sediment. The water depth in places was a few millimetres. *N. dirga* was not found swimming, a fact explained by the undeveloped natatory setae on its antennae and the presence of a thick bristle attached to the last antennular segments which would be useful for crawling. It is likely that the abundant hairs covering the carapace of *N. dirga* are of some use in keeping the animal moist by trapping a water film or bubbles around the shell, and in maintaining the animal's vertical position by the hairs acting as lateral stabilizers when water is depleted within the seeps. Abundant hairs are also

Figs. 35-48. *Reticypris walbu* n. sp. Female paratypes. 35: internal lateral RV; 36: internal lateral LV; 37: external lateral of carapace RV; 38: external lateral of carapace LV. Male paratypes. 39: internal lateral RV; 40: internal lateral LV; 41: external lateral of carapace RV; 42: external lateral of carapace LV. Female paratype. 43: dorsal of carapace. Male paratypes. 44: dorsal of carapace; 45: ventral of carapace. Juvenile. 46: lateral RV. Female paratype. 47: detail of Fig. 35, dorsal area. Male paratype. 48: detail of Fig. 39, postero-dorsal area.

Figs. 35-46: approx. 15x; 47-48: approx. 240x.
Specimens illustrated in Figs. 39-45 have been destroyed.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present on *Mesocypris* ssp. and *Scottia audax* (Chapman, 1961) new comb. which are semi-terrestrial ostracods found in eastern Australia.

D. L. G. Williams provided me with some core material from Strangways Springs in which valves of *N. dirga* were abundant within sandy sediment up to a depth of 1 m below water level.

Subfamily: DIACYPRIDINAE* McKenzie 1978

Genus RETICYPRIS McKenzie, 1978

Reticypris walbu n. sp.
Figs. 35-63.

Holotype: Adult male, AM P28688.

Paratype: Ovigerous female, AM P28689.

Type locality: Pool in Margaret River, S.A. (lat. 29° 22′ 38″ S; long. 136° 46′ 52″ E).

Derivation of name: Walbu in Arabunna terminology meaning rib bone for the saw-like appearance of the dorsal edge of the shell. Walbu relates to the particular myth at the Blanche Cup and Bubbler Springs when a mythological hero captured and cooked in a spring a large snake, discarding the rib bones to form the white encrustations seen at the edge of the spring.

Diagnosis: Saw tooth like ornamentation in the dorsal area of the shell, and posterior edge of both valves with broad denticulation. Shape of hemipenis as in Fig. 60.

Description: Carapace. (External). Holotype adult male: length LV 0.725 mm, RV 0.71 mm; height LV 0.485 mm, RV 0.48 mm. Paratype ovigerous female: length LV 0.82 mm, RV 0.81 mm; height LV 0.54 mm, RV 0.53 mm. Carapace kidney shaped with curved dorsum; ventrum deeply incurved; hexagonal reticulation all over carapace; broad denticulation along posterior edge, and sometimes anterior edge, of valves—this denticulation occurs on a rim that contours both valves all around near flange and continuing in dorsal area where denticulation has appearance of saw (Fig. 48)—greatest height at about 1/3 from anterior, and greatest width at about 2/3 from anterior. LV longer especially in anterior area; overlap of LV over RV dorsally with stronger overlap at 1/3 from anterior (Figs 43-44). Reticulation of valves and denticulation along edge of valves present in juveniles (Fig. 46).

(Internal). Selvage narrow anteriorly and broad posteriorly in both valves; calcified inner lamella at least twice broader than outer lamella anteriorly, whereas nearly absent posteriorly. Hinge: fine groove in RV (Fig. 48) and ridge in LV; in LV, anterodorsally and posterodorsally small extension, for overlapping RV, covering the fine ridge. Central muscle field with inclined row of 3 broad horizontal scars and one behind middle one and a small one in front of top one; 2 mandibular scars below and in front. Radial pore canals numerous and straight. In male 4 rows of seminal vesicles parallel to dorsum and curved anteriorly and posteriorly to form complete tight loop at least posteriorly (Figs 39-40).

Anatomy. Antennula: (Fig. 49); 7 segmented; length/width ratio of last 6 segments: $\frac{7}{12}$, $\frac{7.5}{9}$, $\frac{6}{8}$, $\frac{3.5}{5.5}$, $\frac{3}{3.5}$, $\frac{3.5}{2.5}$; natatory setae almost as long as last 6 segments. No sensory organ seen on 2nd segment.

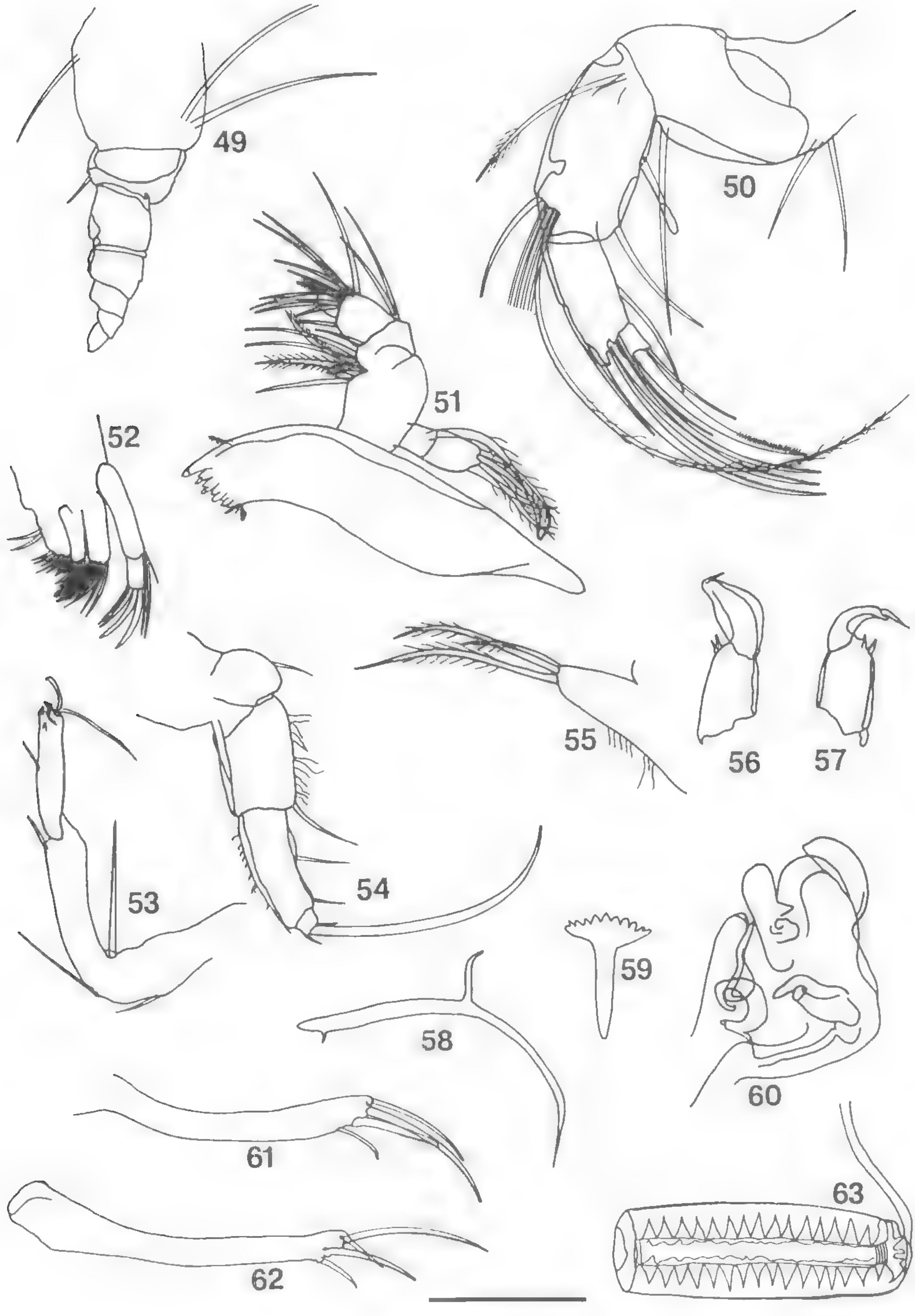
Antenna: (Fig. 50); sexually dimorphic; 2nd segment longer than 3rd; sense club (pitted near its tip) at about 3/5 from distal end of 2nd segment of endopod and about 1/2.4 its length; 5 long natatory setae extending further than tip of claws, and one small one; 4 claws in both sexes with one attached to 3rd segment longer and with 2 rows of longer teeth in male; length/width ratio of 3 endopod segments: $\frac{22}{13}$, $\frac{17}{8}$, $\frac{4}{2.5}$.

Mandible: (Fig. 51); last molar of coxa longer than last 3 and near its base are of 2 short pilose bristles; one pilose and broad bristle above longest molar. Epipod with 5 pilose Strahlen and one basal. Endopod long,

* Originally misspelt as Diacypidinae.

Figs 49-63. *Reticypris walbu* n. sp. Male holotype. 49: antennula (segments only); 50: antenna; 51: mandible; 52: maxillular palp with lobes; 53: thoracopoda II; 54: thoracopoda I. Female paratype. 55: maxillar palp. Male holotype. 56: maxillae palp; 57: other maxillar palp; 58: furcal attachment; 59: rake-like organ; 60: hemipenis; 61: furca. Female paratype. 62: furca. Male holotype. 63: Zenker organ.

Scale: 100μ except for Fig. 59 which is 25μ.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narrow and pilose α and β bristles and longer smooth γ bristle.

Rake-like organ: (Fig. 59); 10 (in male) and 11 (in female) and narrow teeth with interior one bifid.

Maxillula: (Fig. 52); length/width ratio of palp segments: $\frac{14}{3}$, $\frac{4.5}{2.5}$, end of palp with 2 smooth and thick bristles; 2 long setae attached to middle of 1st lobe on posterior side.

Maxilla: sexually dimorphic; in male (Figs 56-57) palps asymmetrical and bearing 2 small pointed setae at base of clasping palp; in female (Fig. 55) 3 pilose setae, each of different lengths, the longest one twice the length of small one.

Thoracopoda I: with penultimate segment undivided; claw as long as last 4 segments; for details of setae see Fig. 54.

Thoracopoda II: 2 terminal setae with longest one 3 times length of hook-shaped one; for details of setae see Fig. 53.

Hemipenis: lateral process banana-shaped and internal one strongly chitinized, brown in colour and cudgel in shape; for outline see Fig. 60.

Zenker organ: (Fig. 63); both ends slightly funnel-shaped and with 16 rosettes.

Furca: sexually dimorphic; 2 strong pectinate claws: anterior one nearly twice length of posterior; in male (Fig. 61) anterior bristle twice length of posterior and longer than posterior claw; in female (Fig. 62) both bristles of equal length and smaller than posterior claw.

Furcal attachment: (Fig. 58); long and strongly arched dorsally with one small dorsal branch curved away from articular extremity near which a small spike occurs ventrally.

Eye: cups of nauplius eye fused.

Colour of shell: (preserved in alcohol) females dark green; male light green.

Remarks: Reticypris walbu differs from *R. herbsti* McKenzie, 1978 and *R. dedeckkeri* McKenzie, 1978 on the following grounds: the shell is reticulated entirely and is broadly denticulated all around the edge of valves (forming a saw tooth-like feature dorsally) whereas in the latter two species the shell is almost smooth anteriorly and posteriorly and bears very fine denticulations along the margin of the shell except in the dorsal area. The hemipenis outline also differs: see Fig. 60 and McKenzie (1978, p. 186, Figs 71, 76). The spike near the articulary extremity of the furcal attachment was not described by McKenzie for *Reticypris* but it was found on topotypic *R. herbsti*. This feature may be diagnostic of the Diacypridinae.

Ecology: All *Reticypris* species are restricted to saline waterbodies and therefore it was not surprising to find *R. walbu* in the pool in Margaret River which Mitchell described as saline to taste. W. Zeidler collected this species at Davenport Spring on 2.xii.1974.

Subfamily: CYPRINOTINAE Bronstein, 1947
Genus: HETEROCYPRIS Claus, 1893

Heterocypris tatei (Brady, 1886)
Figs. 64-96.

Cypris tatei Brady 1886, p. 89, Pl. 8: figs 5-6.

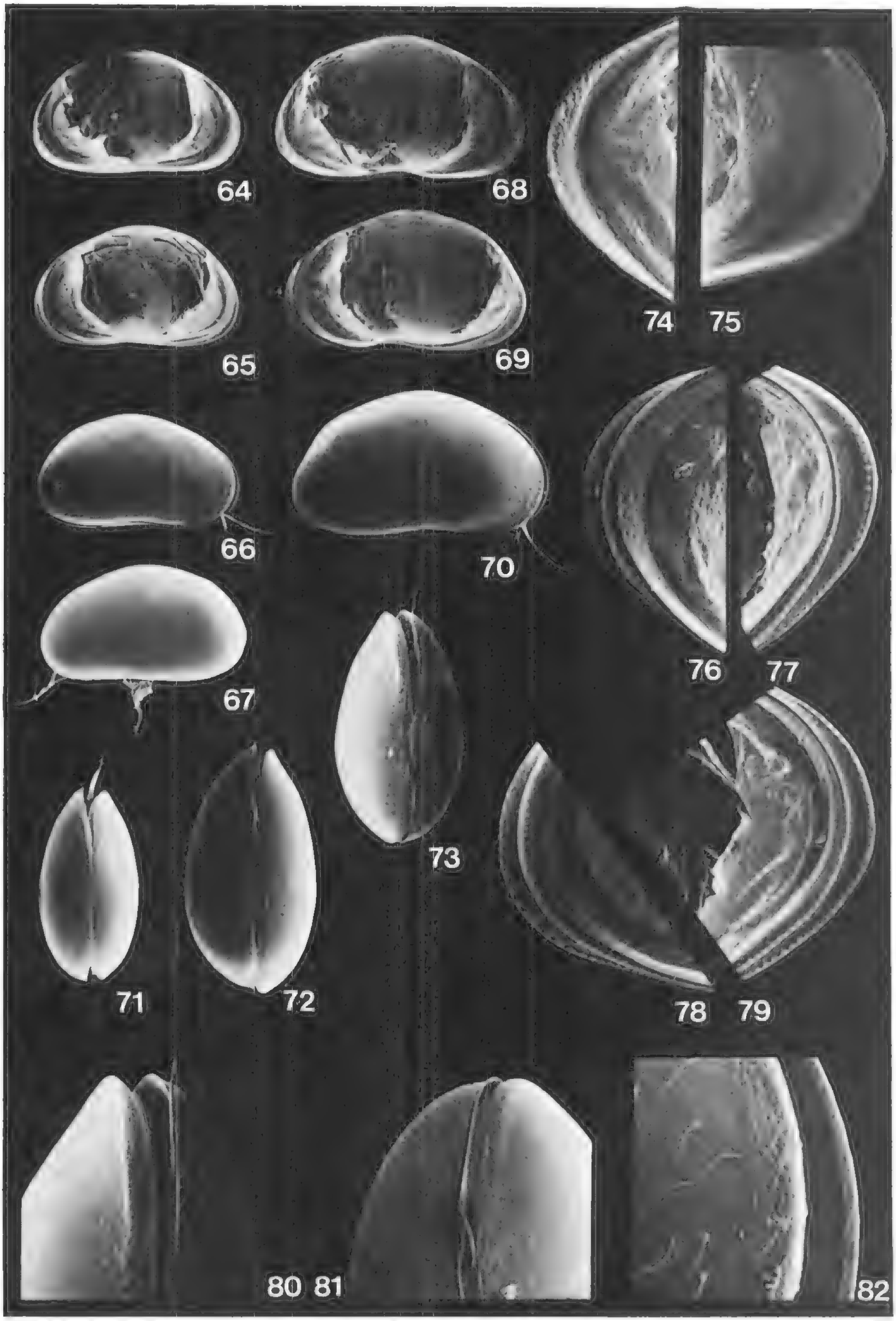
Diagnosis: Outline of hemipenis: lateral lobe "boot-shaped with the "heel" part of the boot tapering outward; angle of "foot" and "leg" part of the boot: 120°; slight indentation on inside of inner lobe at mid-length (see Fig. 90).

Description: A new description is presented here for *H. tatei* because Brady (1886) only described the carapace, and this was done insufficiently and incorrectly.

Carapace. (External). Adult male: length LV 1.86 mm, RV 1.84 mm; height LV 1.00 mm, RV 0.98 mm. Ovigerous female: length LV 2.26 mm, RV 2.20 mm; height LV 1.20 mm, RV 1.20 mm. Holotype (?male): cara-

Figs. 64-82. *Heterocypris tatei* Male 64: internal lateral LV; 65: internal lateral RV; 66: external lateral of carapace RV. 67: external lateral of carapace LV. Female 68: internal lateral LV; 69: internal lateral RV; 70: external lateral of carapace. Male 71: dorsal carapace. Female. 72: dorsal carapace; 73: ventral carapace; 74: detail of Fig. 68, posterior area; 75: detail of Fig. 68, anterior area; 76: detail of Fig. 69, anterior area; 77: detail of Fig. 69, posterior area. Male. 78: detail of Fig. 65, anterior area; 79: detail of Fig. 65, posterior area. Female paratype. 80: detail of Fig. 73, anterior area; 81: detail of Fig. 73, posterior area, upside down position. Male. 82: detail of Fig. 66, anterior area.

Figs. 64-73: approx. 15x; 74-79, 82: approx. 150x; 80-81: approx. 40x.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pace: length 1.63 mm; height 0.92 mm. Shell pseudopunctate and slightly pilose (Fig. 83); bean-shaped in lateral view with dorsum curved and with 2 slight humps: one in middle and other in posterodorsal area (most visible in female); behind posterior hump the dorsum is straight and forms an angle of 60° with the ventrum which is almost flat. Anterior more broadly rounded than posterior. Greatest height at about middle as well as greatest width. LV longer than RV especially anteriorly; in some females RV longer than LV posteriorly. Overlap of LV in antero- and posterodorsal areas and ventrally (Figs 71-73). Brady (1886) illustrated the contrary for the ventral overlap in fig. 6. However, the holotype carapace in the British Museum has an overlap identical to the specimens illustrated here.

(Internal). Anterior and posterior edge of RV with a row of small tubercles (Figs 76-81); selvage broad with RV anteriorly and posteriorly and faintly crenulated (Fig. 76); in RV, calcified inner lamella about same width as outer one anteriorly, and about 4 times width of that in posterior area. Hinges: fine ridge in RV and fine groove in LV. Radial pore canals: straight and numerous. Muscle scars: vertical row of 3, long and narrow, inclined scars with another broad one behind the middle one followed by a small one and another small one below the bottom scar; 2 mandibular scars below and in front of central field.

Anatomy. Antennula: (Fig. 82); 7 segmented; length/width ratio of last 6 segments: $\frac{5}{7.5}, \frac{10}{5.5}, \frac{6.5}{4.5}, \frac{5.5}{3.5}, \frac{3.5}{1.75}, \frac{4}{1.25}$; 2nd segment with small, rod-shaped and transparent, sensory organ at almost 2/5 from its base; 10 long, faintly plumose, natatory setae almost twice the length of last 6 segments together.

Antenna: (Fig. 84); sexually dimorphic; at base of 1st segment of endopod 3 setae of different length: middle one 3 times length of small one; presence of 4 claws in both sexes with the one attached to 3rd segment reaching the tip of the other 3 (in male with 2 rows of long teeth; in female smaller and thin with fine teeth); presence of another external thick setae near the base of the claws, and 2/3 their length, in both sexes.

Mandible: mandibular coxale (Fig. 96) with 7 teeth, last one being longer than penultimate and, near its base, of 3 setae, 2 of which are pilose. Epipod with 5 slightly plumose Strahlen and a small one at its base. Endopod with α bristle narrow and as long as the 2 long straight bristles, β bristle long, narrow and with few straight hairs and γ bristle club-shaped with straight spiky hairs.

Rake-like organ: (Fig. 92); 8 (in female) and 9 (in male) narrow and sharp teeth, the interior one bifid.

Maxillula: (Fig. 86); endopod with 17 plumose Strahlen and a few other bare ones; length/width ratio of palp segments: $\frac{9}{3}, \frac{3.5}{2.5}$; 3rd lobe with 2 toothed Zahnborsten, with 6-4 teeth on anterior one and 4-2 on posterior; broad seta, with pilose tip, at base of 3rd lobe and 4/5 its length.

Maxilla: sexually dimorphic; in male, palps strongly asymmetrical (Figs 88-89); 5 plumose Strahlen on epipod and 13 terminal bristles on protopod and 2 subterminal ones; in female (Fig. 93), endopod with 3 plumose setae, one long in middle and 2 others of equal length and less than half the long one.

Thoracopoda I: penultimate segment divided and bearing 2 setae at anterior, near its base; claw slightly longer than last 2 segments; for details of setae, see Fig. 91.

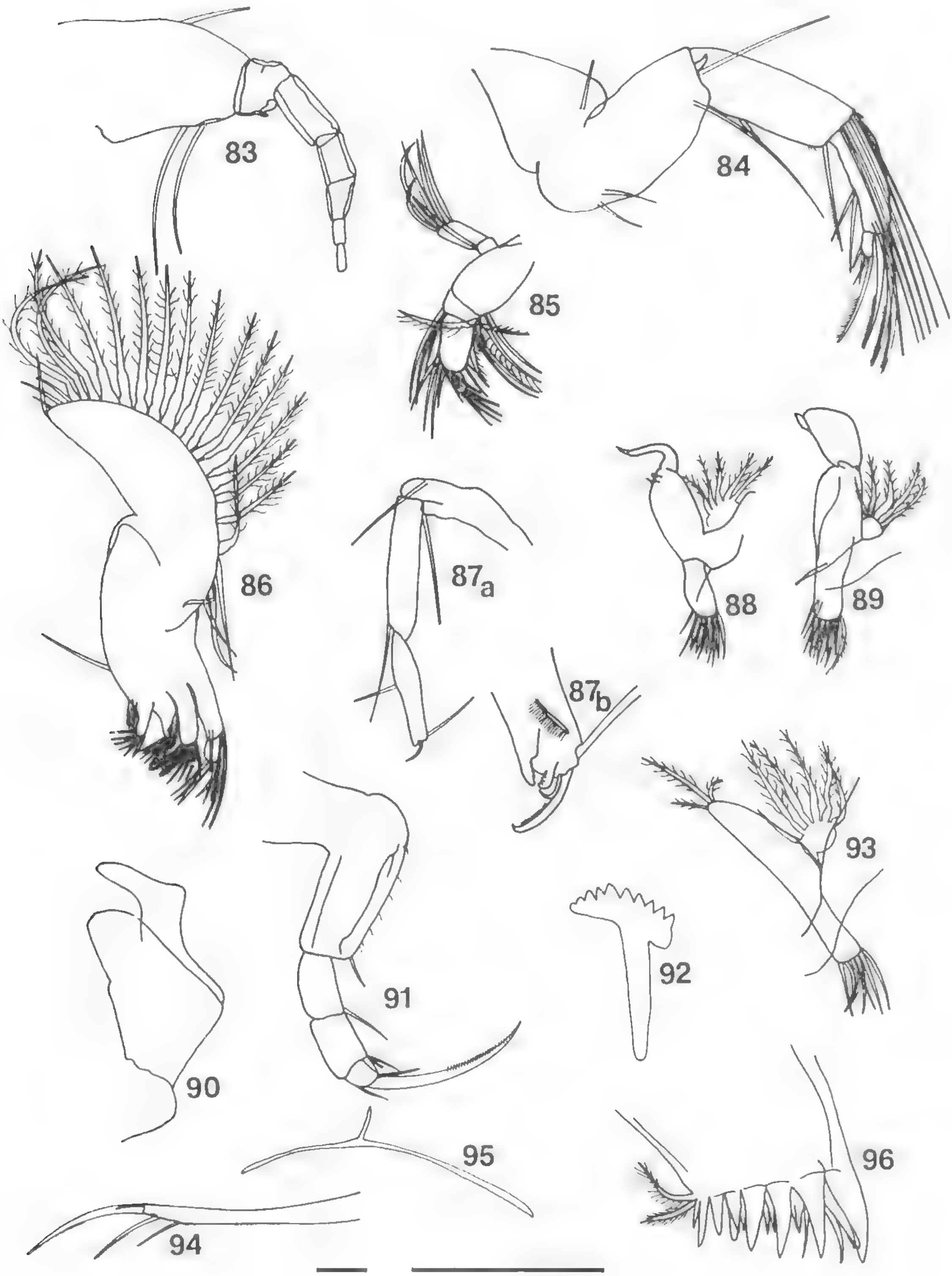
Thoracopoda II: end of last segment with 2 setae, smallest one being hook-shaped; for further details see Fig. 87 a, b.

Hemipenis: lateral lobe "boot" shaped with "heel" part of the boot tapering outward; angle of "foot" with "leg" part of boot: 120°; slight indentation on inside of inner lobe at mid-length; for outline see Fig. 90.

Zenker organ: both ends rounded and 42 rosettes; middle of tube finely striated across length.

Furca: (Fig. 94); shaft with 2 rows of very fine hairs; 2 terminal claws and 2 terminal bristles: anterior bristle small in right furca

Figs. 83-96. *Heterocypric tatei* Male. 83: antennula (segments only); 84: antenna; 85: mandibular endopod. Female. 86: maxillula. Male. 87a: thoracopoda II; 87b: detail of distal end of thoracopoda II; 88: maxilla; 89: other maxilla; 90: hemipenis; 91: thoracopoda I; 92: rake-like organ. Female. 93: maxilla. Male. 94: furca; 95: furcal attachment; 96: detail of mandibular coxale.
Scales: 100μ (large one for Figs. 87b, 92, small one for others).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and longer in left one where it is almost as long as posterior one. Claws unequal: posterior one 2/3 length of anterior.

Furcal attachment: (Fig. 95); slightly curved with dorsal branch very thin and curved away from articular extremity.

Eye: cups of nauplius eye fused; dark brown in colour.

Colour of shell: transparent to white when in alcohol.

Distribution and ecology: The original locality was given by Brady (1886) as "brackish pools in a dry creek at Adelaide". However, the holotype slide was labelled "Brackish Pools, Dry Creek, Adelaide". A river named "Dry Creek" exists in the north of Adelaide and it is thought to be the locality from which Professor R. Tate collected the specimens described by Brady. Part of Dry Creek has been transformed into a drain. *Heterocypris tatei* has been collected by B. D. Mitchell at a temporary pool near Hamilton Hill Homestead, at Coward Springs Railway Bore Swamp and Coward Springs. One emptied carapace was collected by K. F. Walker from Dalhousie Homestead Spring on 4.x.1975. This species has also been collected by J. Arnold on 9.vi. 1977 in a pool at Beringboding Rock, W.A. (lat. 30° 34′ S; long. 118° 29′ E).

This ostracod, as for most species recorded in the genus, is a common inhabitant of temporary pools. It is not surprising therefore to find it in the various pools and swamps in the area studied as well as in one of the springs (Coward Springs) where the conductivity was 6811 mmho. Inhabitants of temporary pools can usually withstand slight salinities but are never found in saline lakes.

Remarks: Outside Australia, the average length for *Heterocypris* species is about 1 mm. *H. tatei* and *H. leana* (Sars 1896) are exceptions. The length of the adult female of the latter species is 2.70 mm and the size of some *Heterocypris* spp. can vary greatly: *Heterocypris aurea* (Sars 1896) described from South Africa had a length of 1.32 mm (male) and 1.60 mm (female) but Daday (1913) recorded for it a length of 2.2 mm (male) and 2.5 mm (female), (McKenzie 1971). The holotype of *H. tatei* is slightly smaller than the specimens described here but the length/height ratio is very similar for Brady's specimens and for those from the Mound Springs area.

It is important to point out the difference in sizes of specimens within a species because many *Heterocypris* species have been distinguished only on the basis of the length and height of the carapace.

Acknowledgements

I wish to thank Mr B. D. Mitchell who collected the ostracods from the mound springs and made available his data and report on the aquatic fauna of the springs. Dr K. F. Walker also made available his collections and data taken at the mound springs made in November 1974. I wish to thank Dr R. W. Ellis for providing, through Mr B. D. Mitchell, Arabunna terms which I used in naming the ostracods.

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VOL. 103, PARTS 7 & 8 30 NOVEMBER, 1979

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A NEW SPECIES OF STREAM-DWELLING HYLID FROG FROM NORTHERN QUEENSLAND

BY MARGARET DAVIES & K. R. MCDONALD

Summary

A new species of hylid frog, Litoria lorica, is described from near Thornton Peak in north Queensland. External morphology and cranial and post-cranial anatomy indicate a relationship with the Litoria nannotis species group. The species is sympatric with L. nannotis, L. rhecola and L. nyakalensis and lives in or near fast flowing streams.

A NEW SPECIES OF STREAM-DWELLING HYLID FROG FROM NORTHERN QUEENSLAND

by MARGARET DAVIES* & K. R. MCDONALD†

Summary

DAVIES, M., & MCDONALD, K. R. (1979) A new species of stream-dwelling hylid frog from northern Queensland. *Trans. R. Soc. S. Aust.* **103**(7), 169-176, 30 November, 1979.

A new species of hylid frog, *Litoria lorica*, is described from near Thornton Peak in north Queensland. External morphology and cranial and post-cranial anatomy indicate a relationship with the *Litoria nannotis* species group. The species is sympatric with *L. nannotis*, *L. rheocola* and *L. nyakalensis* and lives in or near fast flowing streams.

Introduction

About one-third of the known frog fauna of the Australian continent has been described in the last decade (Tyler 1979a). Many of these descriptions arise from the re-examination of existing material, but a large proportion of new species has resulted from greater access to remote areas, and the intense activity generated by faunal surveys.

The faunal survey program of the Queensland National Parks and Wildlife Service has resulted already in the description of *Litoria longirostris* (Tyler & Davies 1977) and *Cophixalus concinnus* (Tyler 1979b). A further undescribed species was collected by J. W. Winter and R. G. Atherton at Alexandra Creek, near Thornton Peak in 1976. The species appears to be a member of the *Litoria nannotis* species group as defined by Liem (1974) and Tyler & Davies (1978).

Here we describe the new species and compare it with other members of the *L. nannotis* species group.

Materials and methods

The specimens reported here are deposited in institutions abbreviated in the text as follows: American Museum of Natural History (AMNH), British Museum of Natural History (BMNH), Queensland Museum (QM), Queensland National Parks and Wildlife Service (QP), South Australian Museum (SAM).

Methods of measurement follow Tyler (1968) whilst the abbreviations used in referring to various features employed in morphometric investigations are: E–N eye to naris distance; HL head length; HW head width; IN internarial span; S–V snout to vent length; TL tibia length. Osteological descriptions follow Trueb (1979). Cleared and stained material was prepared by a slight modification of the method of Davis & Gore (1947) whilst dried skeletal preparations were made following the methods cited by Tyler & Davies (1979).

The following specimens of the *L. nannotis* species group were examined for comparison with the new species. All were collected in Queensland.

Litoria nannotis (Anderson): QPA9-13, 2285-8, Mt Spec; QPA289, 418, 584, 815, 829, Crater Ntl Pk; QPA328, Josephine Falls; QPA792-3, Millstream Falls Ntl Pk; QPN14449-50, Charappa Ck; QPN14201-2, Alexandra Ck nr Thornton Peak; QPN14071, Russell River headwaters; QPN14132, Mt Lewis State Forest. *Litoria nyakalensis* Liem: QPA582, 809, 837, Crater Ntl Pk; QPN14282-3, 14285, 14289, Lake Eacham; QPN14077, Russell River headwaters, 17°24', 145°46'E; QPN14214, Alexandra Ck nr Thornton Peak; QMJ22629, Beatrice Ck, Palmerston Ntl Pk (Paratype). *Litoria rheocola* Liem: QPA292-3, Chena Camp; QPA294-7, Little Fork, Annan River; QPA392, Condoi Ck, Tully Mission Beach Rd; QPA423, Oliver Ck, (between Daintree and Cape Tribulation); QPA813, Millstream Falls; QPN14189-90, 17710, 14206, Alexandra Ck;

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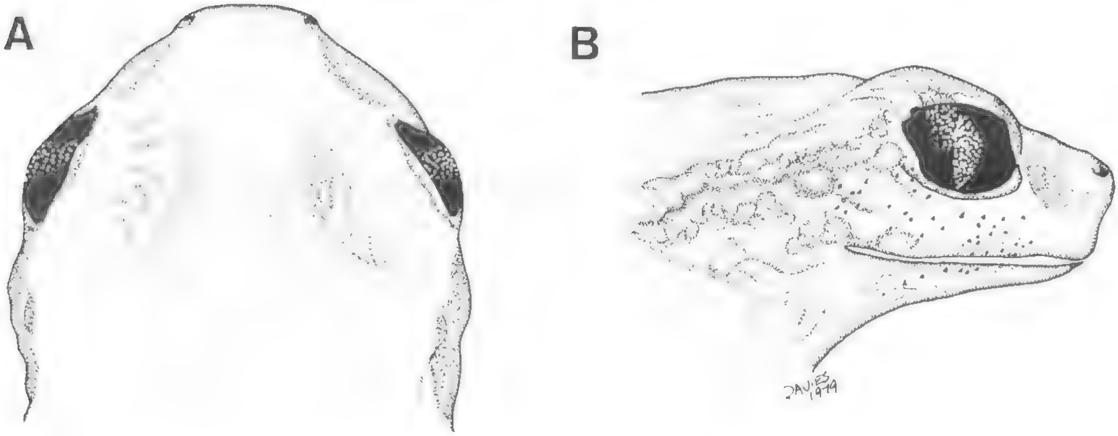

Fig. 1. A, dorsal and B, lateral views of the head of the holotype of *Litoria lorica*.

QPN14281, Lake Eacham; QMJ22644 (Paratype) Cape Tribulation.

Litoria lorica sp. nov.
FIGS 1–3

Holotype: QMJ36090, an adult male collected at Alexandra Creek near Thornton Peak (16°7′, 145°20′) Queensland by J. W. Winter and R. G. Atherton on 10.xii.1976.

Definition: A medium-sized, stream-dwelling species (female 32.9–37.3 mm; males 29.6–33.1 mm S–V length) characterized by poorly webbed fingers, fully webbed toes, moderately long hind limbs, males with spiny nuptial pads and accessory pectoral spines; ova large and unpigmented.

Description of holotype: Head evenly rounded, longer than broad (HL/HW 1.03); head length less than one-third of snout to vent length (HL/S–V 0.34). Snout short, truncate when viewed from above, and in profile (Fig. 1). Nostrils slightly more lateral than superior, situated almost at tip of snout. Distance between eye and naris greater than the internarial span (E–N/IN 1.10). Canthus rostralis well defined and strongly curved, loreal region strongly sloping. Eye prominent, its diameter greater than eye to naris distance by about one quarter. Tympanum small and indistinct. Well-developed glandular supratympanic fold.

Vomerine teeth on short transverse elevations slightly posterior to posterior edges of choanae. Tongue broadly oval and unnotched. Fingers long and slender, lacking lateral fringes and webbed at base (Fig. 2); in order of length 3 > 4 > 2 > 1. Terminal discs on fingers 2, 3 and 4 very well developed and twice width of lateral edges of penultimate phalanx. Disc on first finger reduced. Subarticular and palmar tubercles moderately developed. Supernumerary metacarpal tubercles present on all fingers. Extremely prominent prepollex. Densely spiny nuptial pad present. Forearm moderately robust.

Hind limbs moderately long (TL/S–V 0.59). Toes in order of length 4 > 3 > 5 > 2 > 1 (Fig. 2). Toes almost fully webbed, webbing on outer edge of fourth toes and inner edge of second and third toes reaching the base of the penultimate phalanx and continuing to disc as a broad fringe. Webbing reaches the discs on all other edges of toes. Subarticular tubercles prominent, and small supernumerary metatarsal tubercles numerous. A small oval inner metatarsal tubercle. No outer metatarsal tubercle. Narrow tarsal ridge.

Vocal sac absent.

Dorsum finely tubercular, more prominent tubercles being concentrated on upper eyelids and in tympanic region. Ventral surface granular on thorax abdomen and backs of thighs. Accessory keratinous, conical spines present in clearly demarcated zones upon ventral and lateral surfaces of upper arms and extending very slightly on to chest; a few smaller spines on loreal region, maxillary region and undersurface of mandible.

Dorsum dull slate in preservative. Ventral surface cream with a faint dusting of dark pigment on throat.

Dimensions of holotype: S–V 33.1 mm; TL 19.6 mm; HL 11.1 mm; HW 11.5 mm; E–N 3.4 mm; IN 3.1 mm; E 4.4 mm; T 1.2 mm.

Etymology: The specific name is derived from the Latin *lorica* "breast plate," in reference to the accessory pectoral spines on the male.

Variation

There are nine paratypes: AMNH 103747, (immature ♀), BMNH 1979.7 (adult ♂), QMJ 36091–2 (adult ♂ & adult ♀), SAM R17351 (adult ♀) collected with holotype; QMJ 36093, SAM R17348, 17350 (3 adult ♂♂) (SAM R17348 cleared and stained), 11.xii.1976, type locality; SAM R17349 (adult ♂) 9.xi.1976, type locality. All specimens were collected by J. W. Winter and R. G. Atherton.

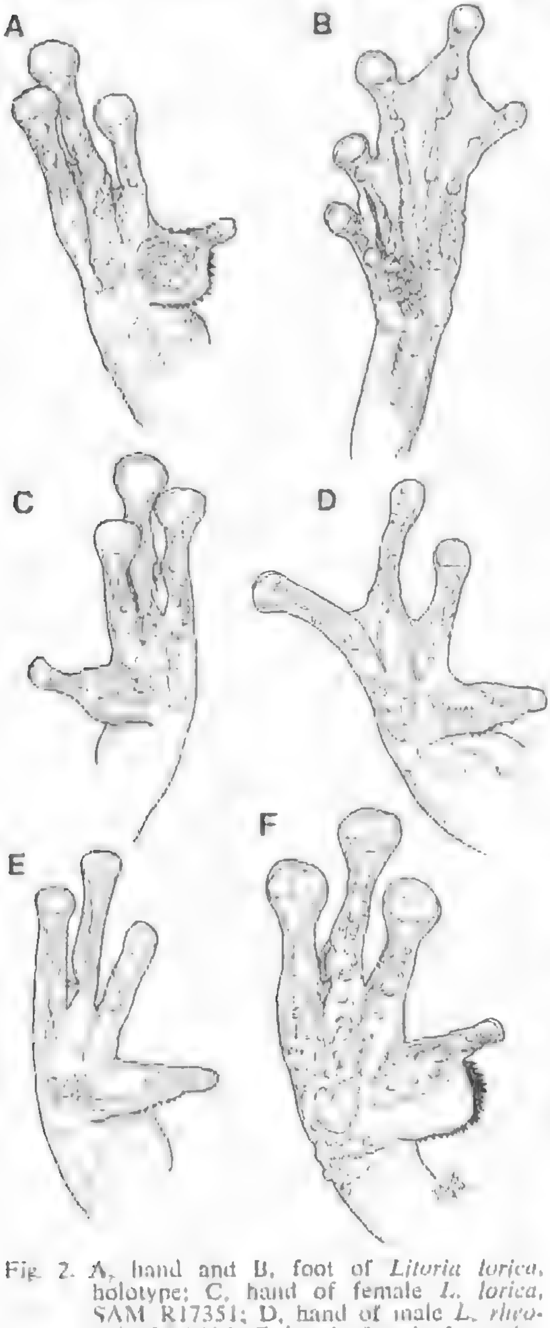

Fig. 2. A, hand and B, foot of *Litoria lorica*, holotype; C, hand of female *L. lorica*, SAM R17351; D, hand of male *L. rheocola* QPA837; E, hand of male *L. nyakalensis* QPA809; F, hand of male *L. nannotis*, QPA815.

The adult males measure 29.6–32.2 mm S–V and the females measure 32.9–37.3 mm S–V. The diameter of an unpigmented egg in the body cavity of SAM R13751 is 2.3 mm. Hind limbs are moderately long and variable (TL/S–V 0.55–0.62). Head width/head length ratios vary from 0.94–1.03. Head length to snout–vent length ratios range from 0.30–0.37 and E–N/IN ratios from 0.85–1.19.

Morphological variation is restricted to degree of distinctness of the tympanum (barely discernible in most of the paratypes) and degree of pigmentation of the gular area, ranging from moderately dense in the gravid female SAM R17351 to barely present in some of the male paratypes.

Forearms of males are more robust than those of females. A well-developed prepollex is present in females as well as males (Fig. 2).

Osteology

Skull moderately robust with moderately well ossified neurocranium (Fig. 3). Moderately large portion of sphenethmoid ossified slightly anteriorly to level of palatines and posteriorly extending about half length of orbit in ventral view. Sphenethmoid does not make bony contact with nasals. Prootic completely fused with exoccipital. Exoccipital not ossified dorsomedially. Crista parotica well developed, short, stocky and laterally barely articulates with slightly expanded otic ramus of squamosal. Frontoparietal fontanelle moderately extensive being overlapped irregularly laterally by moderately slender frontoparietals which extend about two-thirds length of orbit. Orbital edges of frontoparietals straight. Anterior margin of frontoparietal fontanelle formed by sphenethmoid at level slightly less than anterior one-third of length of orbit. Posterior margin undefined owing to absence of medial prootic ossification. Nasals moderately large, widely separated medially, with slenderly acuminate maxillary processes not articulating with deep pars facialis of maxillaries. Palatines moderately long, slightly ridged, expanded slightly laterally, tapering medially to terminate on lateral extremities of sphenethmoid anteriorly

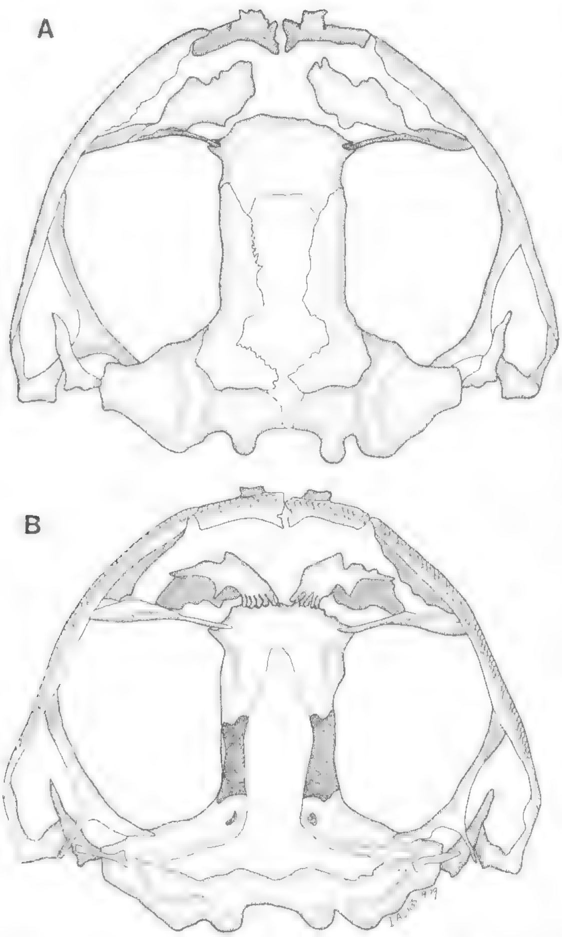

Fig. 3. A, dorsal and B, ventral views of the skull of *Litoria lorica*, SAM R17348.

to level of cultriform process of parasphenoid. Parasphenoid robust with broad, subacuminate, cultriform process and short, moderately broad alary processes, directed slightly posterolaterally and not overlapped by medial rami of pterygoids.

Pterygoid moderately developed with very slender acuminate posterior process. Anterior process in short contact with palatal shelf of maxillary at a level almost three-quarters anteriorly of length of orbit and medial arm moderately long and acuminate. Quadratojugal moderately robust and fully articulated. Squamosals moderately robust; zygomatic ramus slightly longer than otic ramus. Maxillary and premaxillary dentate. Tiny preorbital process on pars facialis of maxillary. Alary process of premaxillaries bifurcate, directed anterolaterally. Palatine processes of premaxillaries moderately well developed, curved posteromedially but do not articulate with each other.

Prevomers reduced anteromedially; alae form anterior and medial margins of choanae. Dentigerous processes moderately short bearing 6–7 teeth and horizontally oriented. Bony columella present.

Pectoral girdle arciferal and robust. Omosternum and xiphisternum present; clavicles slender and abut medially. Scapula slightly shorter than clavicles.

Suprascapula about two-thirds ossified. Humerus greatly expanded with well-developed dorsal and ventral crests.

Eight procoelous non-imbricate presacral vertebrae. Medial dorsal ossification incomplete on presacral I and II. Relative widths of transverse processes: III = Sacrum > IV = II > V = VI = VII = VIII. Sacral daipophyses moderately expanded, ilia extend half way along their length. Urostyle bicondylar with dorsal crest extending for about one-half its length.

Phalangeal formula of hand: 2, 2, 3, 3. Distal tips of terminal phalanges clawed. Very large bony prepollex. Flange present on adjacent metacarpal (I). Phalangeal formula of foot: 2, 2, 3, 4, 3. Tiny bony prehallux. Intercalary structures cartilaginous.

Comparison with other species

(a) *External morphology*: The medium size, slight finger webbing, extensive toe webbing, dull colouration, spiny nuptial pad, lack of vocal sac and large unpigmented ova are a combination of features exhibited by members of the *Litoria nannotis* species group viz. *L. nannotis*, *L. nyakalensis* and *L. rheocola*. *L. lorica* is undoubtedly a member of this species group.

The species can be distinguished from *L. nyakalensis* and *L. rheocola* by the presence of accessory pectoral spines in the male, the indistinct tympanum and the enlarged prepollex (Fig. 2). It can be distinguished from *L. nannotis* (the species to which it seems to be most closely related) by its smaller size (*L. nannotis* male S–V 40.1–53.2 mm, female S–V 46.3–56.0 mm), its truncate snout (Fig. 6) and the terminal position of the nares. In addition, *L. nannotis* males have more accessory spines in the head region, and on the forearm and thighs, and have a more robust forearm than *L. lorica*.

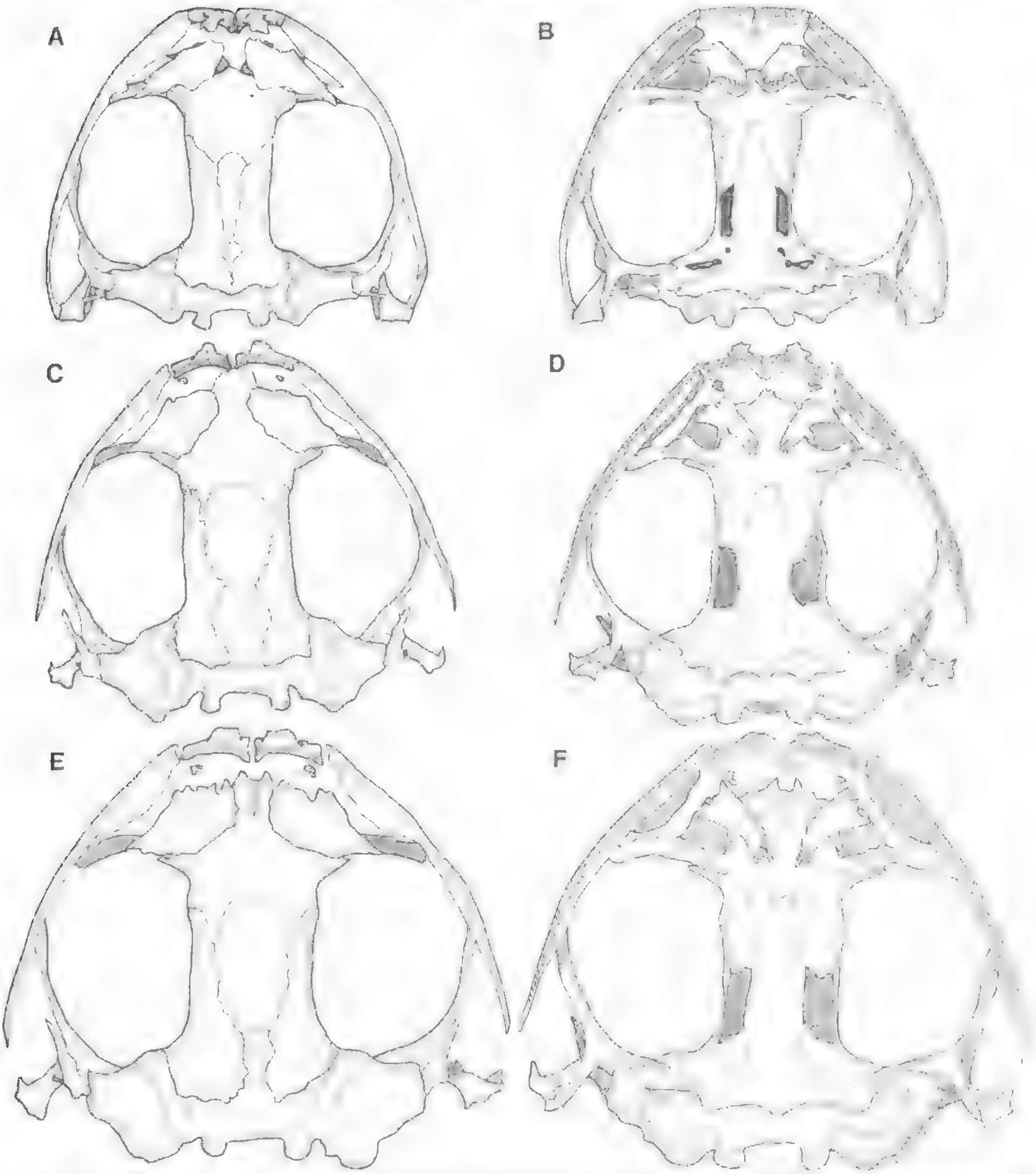

Fig. 4. A, dorsal and B, ventral views of the skull of *Litoria nannotis*, NP N14312; C, dorsal and D ventral views of the skull of *L. rheocola*, NP N14281; E, dorsal and F, ventral views of the skull of *L. nyakalensis*, NP N14284.

(b) *Osteology*: The skulls of *L. nannotis*, *L. nyakalensis* and *L. rheocola* are illustrated in Fig. 4. *Litoria lorica* can be distinguished from *L. nannotis* by reduced ossification of the neurocranium, the anterodorsally projecting alary processes of the premaxillaries (accounting for the more truncated snout shape in *L. lorica*), the lack of a pronounced preorbital process on the pars facialis of the maxillary, larger exposure of the frontoparietal foramen, the stockier crista parotica, the longer dentigerous processes of the prevomers and the very slender medial extremities of the palatines.

Posteranially, *L. nannotis* differs from *L. lorica* in having poorly expanded sacral diapophyses and the relative width of the

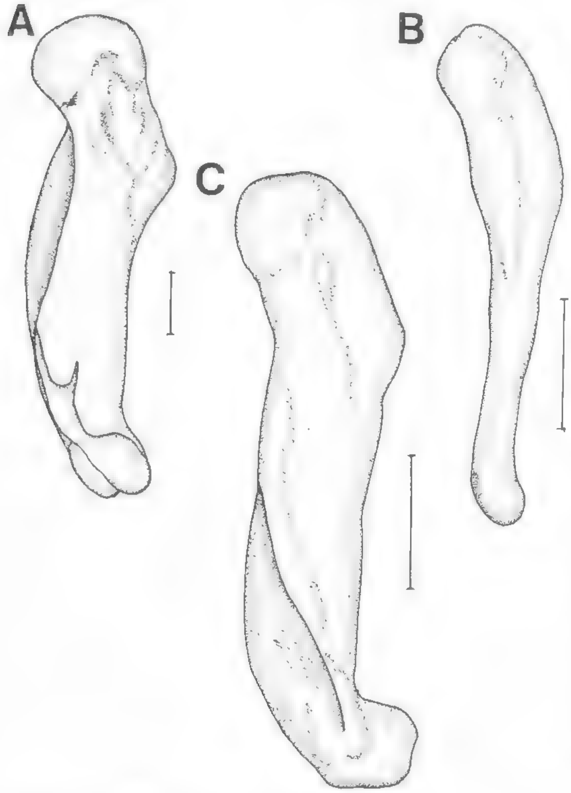

Fig. 5. Lateral view of humerus of A, male *Litoria nannotis*, B, male *L. rheocola* and C, male *L. nyakalensis*. Scale bar = 2 mm

transverse processes of the presacral vertebrae of III > Sacrum > IV > II > V = VI = VII = VIII.

The bony prepollex of *L. nannotis* is larger than in *L. lorica* and a number of flanges are present on the adjacent metacarpal compared with the single flange in *L. lorica*. Presence of humeral flanges dorsally and ventrally in *L. nannotis* (Fig. 5) is similar to the condition in *L. lorica* although these are more pronounced in the former species.

L. lorica differs from *L. rheocola* in having reduced ossification of the neurocranium, no contact between sphenethmoid and nasals, an elongate frontoparietal foramen, a complete quadratojugal, longer dentigerous processes of the prevomers and slender medial extremities of the palatines.

Postcranially, medial separation of the coracoids is less in *L. lorica* than in *L. rheocola*. Humeral flanges are poorly developed in *L. rheocola* (Fig. 5) and there is no flange on the adjacent metacarpal to the narrower bony prepollex. Relative widths of the transverse processes of the presacral vertebrae in *L. rheocola* are III > Sacrum = IV > II > V = VI = VII = VIII. The intercalary structures are ossified.

L. lorica can be distinguished from *L. nyakalensis* by reduced ossification of the neurocranium, absence of nasal contact with the sphenethmoid, an elongate frontoparietal foramen, longer dentigerous processes of the prevomers and slender medial termination of the palatines.

Postcranially, *L. lorica* and *L. nyakalensis* are similar with comparably developed humeral and metacarpal flanges and prepollices. The relative widths of the transverse processes of the presacral vertebrae in *L. nyakalensis* are III > Sacrum > II > IV > V = VI = VII = VIII. Intercalary structures are bony.

Larval morphology: The tadpole is unknown but the habitat preference of the adult indicates that it is probably a torrent-adapted form.

Habitat: The type series was collected on granite boulders in notophyll vine forest in the splash zone near turbulent, fast-flowing water. At the type locality *L. lorica* is sympatric with *L. nannotis*, *L. rheocola* and *L. nyakalensis*.

L. nannotis is usually found in the splash zone of rapids and waterfalls, but some specimens of both sexes have been collected on trees away from these areas. *L. nyakalensis* is usually found on branches overhanging streams, rarely on rocks, whilst *L. rheocola* is found on rocks and sometimes on overhanging branches near broken water.

Differing habitat preferences are exhibited by each of the four species although *L. nannotis* and *L. lorica* seem to exhibit the least separation. Further data should clarify this situation.

Distribution: *L. lorica* has been collected only at the type locality of Alexandra Creek near Thornton Peak.

The Litoria nannotis species group

Liem (1974) discussed the three species of the *L. nannotis* group then known. With the description of *L. lorica* and further data now available to us on the other members of the group, some additions to Liem's descriptions are necessary.

On a number of morphological and osteological criteria the group falls naturally into two species pairs: *L. nannotis* and *L. lorica*, and *L. rheocola* and *L. nyakalensis*; these fea-

tures include expansion of the discs (Fig. 2) secondary sexual characters, condition of the quadratojugal (Fig. 4) and intercalary structures. Whilst there is little difficulty in separating members of the former pair from each other and from the other pair, and the males of the second pair from each other, preserved females and non-breeding males of *L. rheocola* and *L. nyakalensis* are difficult to distinguish on external morphology alone.

A great deal of intraspecific variation occurs in many characters. For example, live specimens of *L. nyakalensis* are usually, but not always, pinkish on the ventral surface, and this colouration invariably disappears in preservative. Head shape varies slightly within the group (Fig. 6) but state of preservation can distort this character. Hand and foot webbing show slight differences between the species, but again intraspecific variation occurs. The tympanum is generally indistinct or not visible externally in *L. lorica* and *L. nannotis*, whereas in *L. rheocola* and *L. nyakalensis* it is usually distinct.

Vocal sacs are absent in all members of the species group, but males of *L. rheocola* and *L. nyakalensis* are capable of depressing the submandibular region during vocalization (M. J. Tyler, pers. comm.).

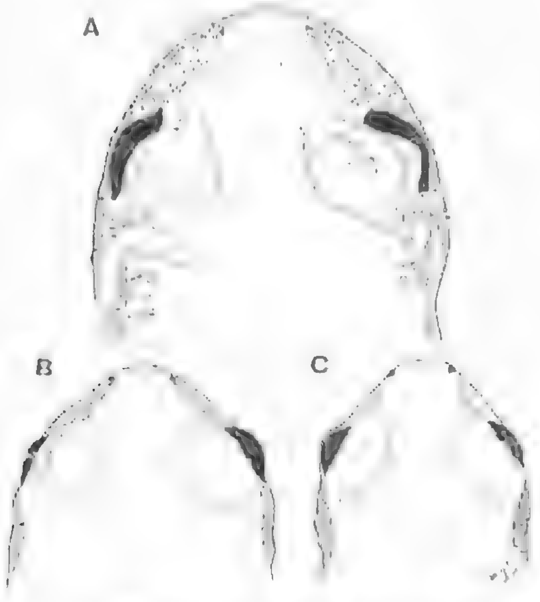

Fig. 6. Dorsal view of head of A, *Litoria nannotis*, B, *L. nyakalensis* and C, *L. rheocola*.

The one morphometric measurement that Liem used to distinguish members of the group —the relationship between eye to naris distance and internarial span was found to be inconsistent in the series of frogs examined by us (*L. nannotis* E-N/IN 0.84–1.24, *L. rheocola* 0.86–1.15, *L. nyakalensis* 0.88–1.35). However, we find that the head length to head width ratio separates *L. rheocola* from *L. nyakalensis*.

Osteological comparisons are between males because females of *L. nyakalensis* have not been available to us for study. Many of the osteological features separating *L. rheocola* and *L. nyakalensis* (such as development of humeral crests and metacarpal flanges, associated with the development of the forearm and prepollex) may be sexually dimorphic.

The following is a key to the species group.

1. Snout truncate; nostrils terminal; S–V < 40 mm 2
   Snout rounded; nostrils opening laterally, slightly posteriorly to end of snout; S–V > 40 mm . . . . *L. nannotis*
2. Nuptial asperities spinous; accessory spines absent; tympanum usually distinct; prepollex not greatly enlarged; moderately large discs; intercalary structures bony 3
   Nuptial asperities spinous; accessory spines on pectoral region; tympanum usually indistinct; prepollex enlarged; discs large; intercalary structures cartilaginous . . . . . . *L. lorica*
3. Nuptial spines fine; nuptial asperities small; ventral surface of posterior portion of body usually cream in life; HL/HW > 1.06 . . . . *L. rheocola*
   Nuptial spines coarse; nuptial asperities moderately large; ventral surface of body usually cream with a reddish tinge in life; HL/HW < 1.06 . . . . *L. nyakalensis*

Acknowledgments

This work was supported by an Australian Research Grant Committee award to M. J. Tyler. For the loan of paratypes of *L. rheocola* and *L. nyakalensis* we are grateful to Mr G. J. Ingram, Queensland Museum. M. J. Tyler critically read the manuscript and his comments are greatly appreciated. We are grateful to the Queensland National Parks and Wildlife Service for the opportunity to examine and describe the new species.

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SOME TETRAMERIDAE (NEMATODA: SPIRURIDA) FROM AUSTRALIAN BIRDS

BY PATRICIA M. MAWSON

Summary

Tetrameres (Petrowimeres) anseranas n.sp. described from Anseranas semipalmata is a large species with two rows of spines throughout the body length, left spicule 1/4-1/5 body length, spicule ratio 20-22. T. (Gynaecophila) dacelonis n.sp. described from Dacelo novaeguineae is a small species with four rows of spines, of which dorso-lateral are incomplete, and a single spicule. T. (Tetrameres) greeni n.sp., (syn. T. pelecani in part), and Microtetrameres pelecani (syn. Tetrameres pelecani) are described from Pelecanus conspicillatus, and their synonymy discussed. T. greeni is distinguished from congeners by presence of caudal alae in the male. M. pelecani Skrjabin is a probable secondary homonym of M. pelecani (Johnston & Mawson).

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Summary

MAWSON, P. M. (1979) Some Tetrameridae (Nematoda: Spirurida) from Australian birds. *Trans. R. Soc. S. Aust.* **103**(7), 177-184, 30 November, 1979.

Tetrameres (Petrowimeres) anseranas n.sp. described from *Anseranas semipalmata* is a large species with two rows of spines throughout the body length, left spicule 1/4-1/5 body length, spicule ratio 20-22. *T.* (*Gynaecophila*) *dacelonis* n.sp. described from *Dacelo novaeguineae* is a small species with four rows of spines, of which dorso-lateral are incomplete, and a single spicule. *T.* (*Tetrameres*) *greeni* n.sp., (syn. *T. pelecani* in part), and *Microtetrameres pelecani* (syn. *Tetrameres pelecani*) are described from *Pelecanus conspicillatus*, and their synonymy discussed. *T. greeni* is distinguished from congeners by presence of caudal alae in the male. *M. pelecani* Skrjabin is a probable secondary homonym of *M. pelecani* (Johnston & Mawson).

Other records are of the species *T. globosa* Linstow and *T. gubanovi* Shigin.

Introduction

Most of the nematodes recorded here were taken from birds dissected by the author; others were donated by other collectors. Some Tetrameridae from Australian birds have already been described, and those dealt with here are additional ones (Johnston & Mawson 1941, 1949, 1951; Mawson 1968, 1977).

Chabaud (1975) divides the Tetrameridae into subfamilies, and places *Microhadjella* Jogis and *Tetrameres* Creplin in the Tetramerinae. *Microtetrameres* he considers a subgenus of *Tetrameres*, on the grounds that the head structures of the two groups are similar though not sufficiently studied. In practice however they are readily separable, the females by the body shape, and the males usually by the type and arrangement of the caudal papillae, though this latter is noted more easily in the actual specimen than in line drawings. *Microtetrameres* is retained as a genus here.

Chabaud also refers to the unsatisfactory definitions for the subgenera usually attributed to these genera. In the case of *Tetrameres*, the three subgenera have in the past been separated by the absence of body spines (*Gynaecophila*) and by the presence (*Petrowimeres*) or absence (*Tetrameres*) of lateral cuticular appendages; however as Chabaud (1975) and Mollhagen (1976)[1] state, the spines are sometimes very few and/or very small. Mollhagen after examining representatives of many species, separates the three subgenera by the absence (*Tetrameres*) or presence, of dorsal and ventral labia, and further by the presence (*Petrowimeres*) or absence (*Gynaecophila*) of anterior lateral flanges (lateral cuticular appendages or cordons of some authors).

In the case of *Microtetrameres*, a subgenus *Gubernacules* has been proposed for species in which there is a gubernaculum; this structure is sometimes distinct, but in many cases indefinite, so that this is an unsatisfactory subdivision, and is not used here.

The specific identification of either *Microtetrameres* spp. or *Tetrameres* spp. from females only is, at the present state of knowledge, impossible. In cases where only the female is present in collections listed below, indentification rests only on similarity to other

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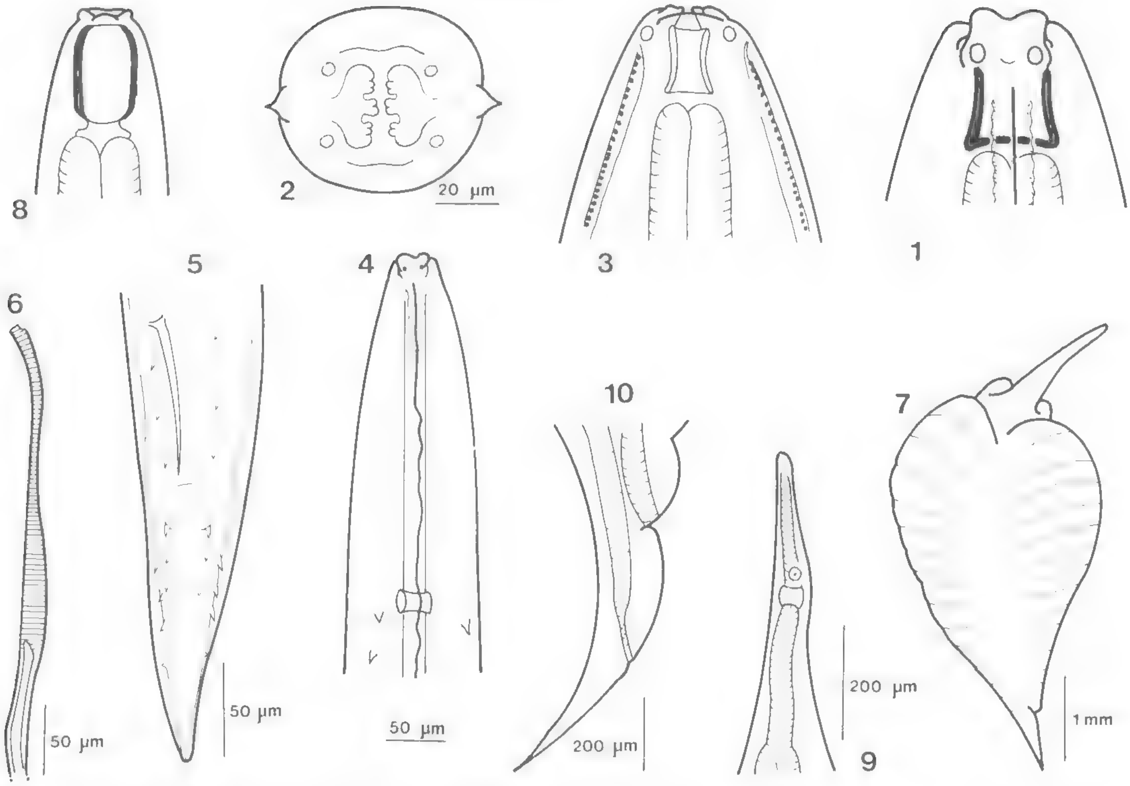
[1]Mollhagen, T. R. (1976) A study of the systematics and hosts of the parasitic nematode genus *Tetrameres* (Habronematoidea, Tetrameridae). Dissertation in Zoology, Graduate Faculty of Texas Tech. University.



Figs. 1-10. *Tetrameres anseranas.* Figs. 1-3. Head of male, in lateral, en face and median views. Same scale. Fig. 4. Anterior end of male. Fig. 5. Posterior end of male. Fig. 6. Proximal end of left spicule. Fig. 7. Female, entire. Fig. 8. Head of female. Fig. 9. Anterior end of female. Fig. 10. Posterior end of female.

females occurring with males. Points considered in comparison of females are the shape and size of the buccal capsule and of the egg.

Two of the species described below are from the Australian pelican. The only record of Tetrameridae from this host is that of *Tetrameres pelecani* Johnston & Mawson (1942a) described from one male, and later redescribed by them (1942b) from three males and a young female. Mollhagen (1976) considered *T. pelecani* incertae sedis, pointing out that the narrow buccal capsule and few caudal papillae described for the single male of the original description were not typical for the genus. Further, though the second description noted more caudal papillae, it also noted the presence of narrow caudal alae, not otherwise recorded for the genus, and moreover that there are discrepancies in the measurements given in the two descriptions. Recent collections from pelicans include female *Tetrameres* and female *Microtetrameres* (sometimes in the same host bird) and with them two species of male tetramerids, neither provided with body spines. These males have been compared with the specimens previously identified as *T. pelecani* (Johnston & Mawson 1942a, 1942b). One is identified as *Microtetrameres* sp. because of the number, arrangement, and shape of the caudal papillae. This is similar to the single male first described as *Tetrameres pelecani,* and this species must now be transferred to *Microtetrameres.*

The other species of male is referred to *Tetrameres.* The head structure, spicules, shape of the tail and type of caudal papillae, all agree with this genus. Although there are narrow caudal alae, not previously described for *Tetrameres,* the specimens are now described as a new species of the genus. The specimens identified as *T. pelecani* by Johnston & Mawson (1942b) have been examined and belong to this species.

Tetrameres (Petrowimeres) anseranas n.sp.

FIGS 1–10, 33-35

Host and localities: *Anseranas semipalmata* (Latham), from Humpty Doo, N.T. (12♂, 41♀).

Male: Body length 7.6–9.2 mm. Anterior flanges present, 90–120 μm long, poorly developed and without freely projecting ends posteriorly, much more clearly seen in S.E.M. preparation (Fig. 33). Lateral alae present, commencing at bases of pseudolabia and extending nearly to cloaca, each supported in region of flange by intracuticular sclerotised rod. Body spines in two subventral rows, most anterior spine just behind level of nerve ring, two rows continuing to cloaca; spines about same size throughout body length but closer together in oesophageal region.

Head with two lateral pseudolabia and dorsal and ventral labia. Pseudolabia depressed in lateral line so that they appear bilobed. Labia strongly cuticularized. Three bilobed teeth on inside of each pseudolabium. Cervical papillae 280–310 μm from head, each trifid, central spine the longest (Fig. 34).

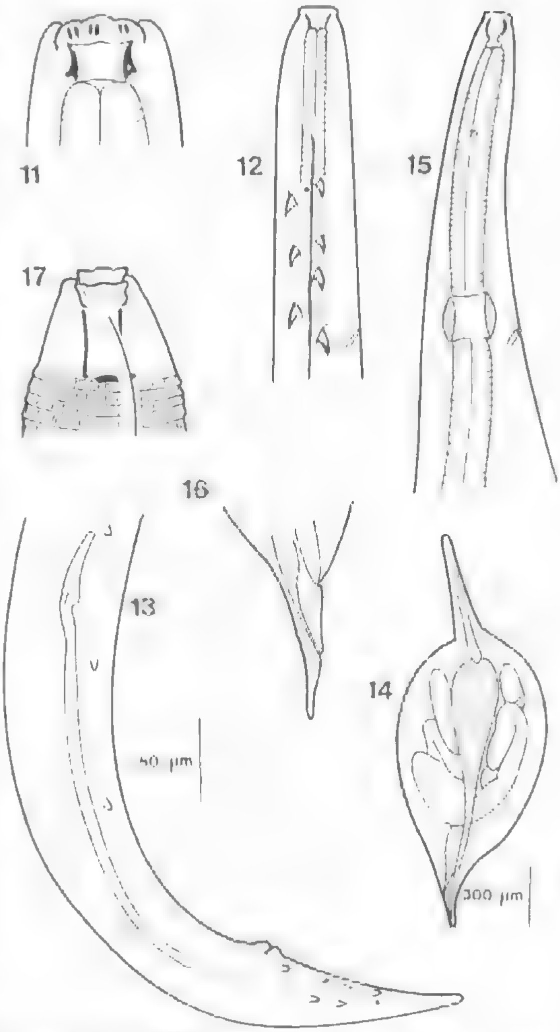
Buccal capsule 30–35 μm long, lateral diameter 12 μm, dorso-ventral 22 μm. Muscular part oesophagus not clearly demarcated from glandular. Nerve ring at 380–400 μm from head, excretory pore just behind this.

Tail 300–380 μm long, tapering to rounded end. Caudal papillae digitiform, three pairs subventral and three pairs sublateral (Fig. 5). Phasmids present. Left spicule 4.6–5.5 mm long, with cylindrical hilt (Fig. 6) 230–250 μm long. Right spicule 155–200 μm long, its proximal end slightly expanded. Spicule ratio 20–30. Gubernaculum absent. In a few specimens left spicule completely absent, and in one of these a piece of (?)spicule sheath projects from cloaca, indicating that the spicule has been completely everted and has broken away.

Female: Body pear-shaped, with widest part anterior to midlength. Total length up to 5.7 mm, maximum diameter 2.3 mm. Lips not as prominent as in male, but dorsal and ventral labia distinct. Buccal capsule cylindrical, narrower at each end, 26–28 μm long, 36–37 μm external width at midlength. Oesophagus about 2.0 mm long, its muscular part 500–530 μm. Nerve ring 240–250 μm from head, excretory pore just behind this. Cervical papillae setiform, distinct, not trifid, just in front of nerve ring.

Tail 380–440 μm long, tapering to blunt point. Vulva 700–830 μm from posterior end. Embryonated eggs bi-operculate, without polar filaments, 50–55 μm long, 20–22 μm wide.

In measurements *T. anseranas* is closest to *T. australis* Johnston & Mawson but in this species there are four rows of spines. The only other species in which there are both lateral flanges and two rows of spines is *T. indiana* Ali, and in this the left spicule is much shorter and the spicule ratio less. As the flanges in *T. anseranas* are so poorly developed and may easily be missed, it has been compared with species without flanges but with two complete rows of spines, but differs from any of these in the length of the left spicule and the large body size.



Figs. 11-16. *Tetrameres dacelonis.* Fig. 11. Head of male. Fig. 12. Anterior end of male. Fig. 13. Posterior end of male. Fig. 14. Female, entire. Fig. 15. Anterior end of female. Fig. 16. Posterior end of female.
Fig. 17. *Tetrameres gubanovi.* Anterior end. (Figs. 12, 13 & 15 to same scale).

Tetrameres (Gynaecophila) dacelonis n.sp.
FIGS 11–16

Host and localities: *Dacelo novaeguineae* (Hermann) from Brisbane, Qld (1 ♂, 20 ♀); A.C.T. (2 ♀).

Male: Length 2.6 mm. Lateral alae present, from just anterior to cervical papillae to about two thirds body length. Four rows of well developed spines, the first at level of cervical papillae (Fig. 12); dorsal rows end about 1820 μm from head, and spines in all rows much smaller, papilla-like and more sparse from about 1250 μm from head. Oesophagus 580 μm long, its muscular part 210 μm; nerve ring 130 μm, cervical papillae 105 μm, and excretory pore 190 μm, from anterior end of worm. Buccal capsule well sclerotised, 12 μm long, 12 μm maximum external diameter. Dorsal and ventral labia present, pseudolabia trilobed. Teeth apparently present, seen only in lateral view.

Single spicule 280 μm long, its hilt 50 μm long (Fig. 13). Tail 115 μm long, caudal papillae elongate, four pairs subventral, two pairs lateral.

Female: Gravid female widest anteriorly, tapering more or less gently to tail, depending on number of eggs. Total length up to 2.4 mm (Fig. 14). Oesophagus up to 800 μm long. In specimen with oesophagus 700 μm, muscular part of oesophagus 290 μm, distance from anterior end of nerve ring 170 μm, of cervical papillae 80 μm, of excretory pore 135 μm. Buccal capsule barrel shaped, 15 μm long, 11 μm external diameter at widest part.

Body tapering from vulva to rounded point at tip of 110 μm long tail, with pair of elongate phasmids 80 μm from tip. Vulva 250 μm from anus. Embryonated eggs 45–48 μm by 21–22 μm, without opercular or polar filaments.

The only record of *Tetrameres* sp. from Alcedinae is of one female, not identified to species, from *Megaceryle alcyon,* U.S.A. (Mollhagen 1976). *T. prozeskyi* Ortlepp has been recorded from two hornbills (*Lophoceros* spp.) and *Tetrameres* sp. from *Merops* sp. (Borgarenko 1960).

The measurements of the male from *Dacelo* are close to those given by Ortlepp (1964) and Mollhagen (1976) for *T. prozeskyi,* but the spines in the latter species start just behind the head, and are distinctly larger; moreover there are no dorsal or ventral labia.

Tetrameres gubanovi Shigin
FIG. 17

Tetrameres gubanovi Shigin, 1957, p 256. From *Colymbus cristatus,* USSR (2 ♂).

Host and localities: *Podiceps cristatus* L., Goolwa and Purnong, S. Aust. (8 ♂, 10 ♀); *Tachybaptus novaehollandiae* (Stephens), Barren Box Swamp, N.S.W. (2 ♂, 3 ♀).

T. gubanovi is the only species recorded in which there are short longitudinal striae on each cuticular annulus at the anterior end of the body, giving a striking appearance (Fig. 17). In the present specimens these striae continue, becoming less distinct, over about two thirds of the oesophageal region.

The measurements of the male worms from the hosts given above are: length 6.5–7.4 mm, oesophagus 1300–1350 μm, left spicule 4.0–4.8 mm, right spicule 150–180 μm, spicule ratio 24–26, tail 380–400 μm. The most anterior hooks lie about 300 μm from the head; there are four pairs of subventral and three pairs of sublateral caudal papillae.

Tetrameres globosa Linstow
FIG. 36

Tetrameres globosa Linstow, 1879, p. 175, from *Fulica atra.*

Hosts and localities: *Porzana pusilla* (Pallas), Beachport, S. Aust. (6 ♂, 2 ♀); *P. fluminea* (G), Glenelg (5 ♂), Mt Mary (1 ♀); Beachport (6 ♂), L. Alexandrina (6 ♂, 12 ♀) S. Aust.; Alice Springs, N.T. (1 ♀); *P. tabuensis* (Gmelin), Langhorne Creek, S. Aust. (3 ♂).

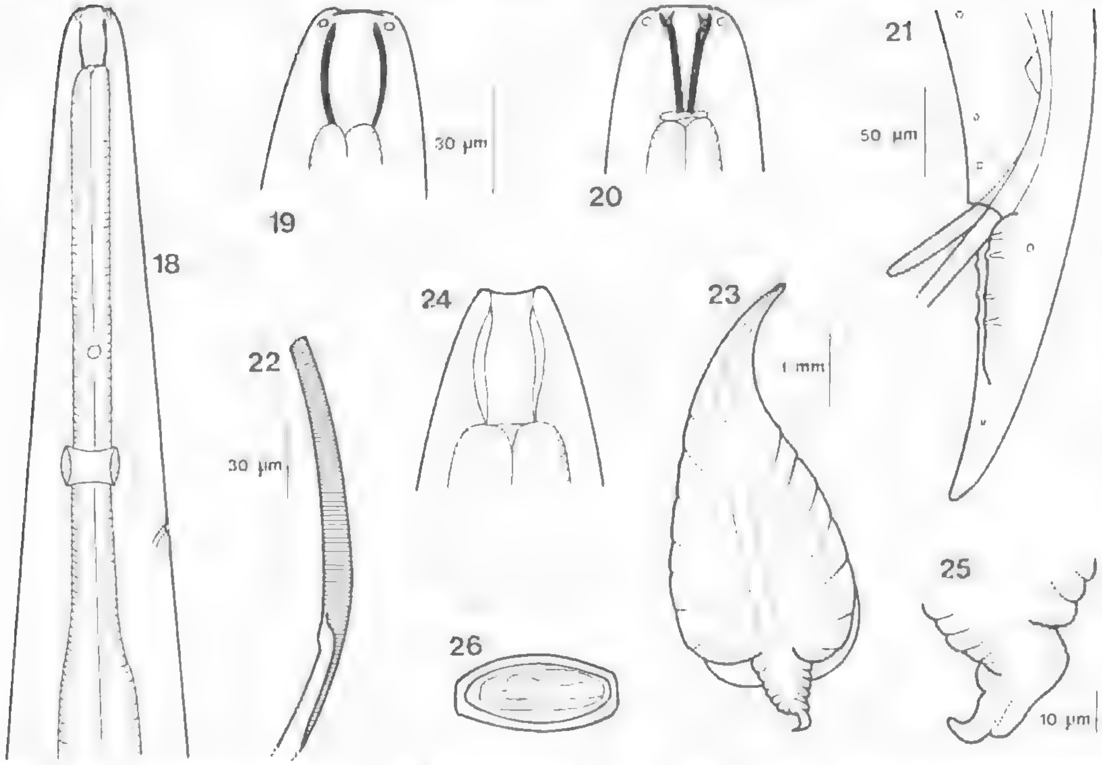
The specimens listed above agree generally with records tabulated by Mollhagen (1976). The differences are small—the tip of the left spicule is rounded, not pointed, and there are very narrow lateral alae. Measurements: males: 1.9–2.5 mm long, oesophagus 560–900 μm (1/2.8–3.4 of body length); single spicule 190–310 μm long, with hilt 30–38 μm; tail 150–180 μm.

Tetrameres (Tetrameres) greeni n.sp.
FIGS 18–26

syn. *Tetrameres pelecani* sensu Johnston & Mawson, 1942b, p. 185, nec 1942a.

Host and localities: *Pelecanus conspicillatus* Temminck, Brisbane, Qld.

Male: Length 4.4–6.2 mm. Head with low trilobed lateral lips, no dorsal or ventral lips. Mouth oval, teeth represented by four submedian cuticular ridges. Buccal capsule 30–35 μm long, wider dorso-ventrally than from side to side. Oesophagus 800–1100 μm long, about a fifth to a sixth of body length, with muscular



Figs. 18-26. *Tetrameres greeni.* Fig. 18. Anterior end of male. Figs. 19, 20. Lateral and median views of head of male. Fig. 21. Posterior end of male. Fig. 22. Proximal end of left spicule. Fig. 23. Female, entire. Fig. 24. Head of female. Fig. 25. Posterior end of female. Fig. 26. Embryonated egg. (Figs. 19, 20, 23 & 25 to same scale; Figs. 18 & 21 to same scale).

part 290– 330μm long. Cervical papillae, nerve ring, and excretory pore respectively 175–200 μm, 200–230 μm and 220–280 μm from anterior end.

Lateral alae absent, and no somatic spines observed but two subventral rows of very small papillae extend from cloaca to about proximal end of left spicule. Tail rounded at tip. Four pairs of elongate post-anal subventral papillae supported by distinct narrow alae and a pair of lateral papillae on the proximal half of tail and a pair of phasmids on distal half.

Left spicule 800–1000 μm long, about a fifth to a sixth body length, with long cylindrical hilt (90–100μm). Right spicule 125–200 μm long. Spicule ratio 5.0–7.7. Gubernaculum absent.

Female: Largest females somewhat pear-shaped, with thickest part of body posterior to midlength. Overall length of body up to 5.5 mm, maximum width 2 mm. Buccal capsule barrel-shaped, 33–35 μm long, diameter 20–21 μm at widest part. Oesophagus 1400–1900 μm long, its muscular part 310–500 μm long. Nerve ring 200–300 μm from head. Excretory pore just behind nerve ring.

Body narrows suddenly a little in front of a vulva, is strongly constricted at vulva, then tapers to tip of tail; body posterior to vulva directed dorsally in all specimens (Fig. 25). Tail 100–120 μm long, vulva 200–300 μm in front of anus. Embryonated eggs 44–45 μm by 20–23 μm; polar threads absent, thickened shoulders at each end suggest presence of opercula but these not visible.

The male of this species is distinguished from all others described for the genus by the presence of caudal alae. Apart from the alae, it seems closest to the four species grouped by Mollhagen (1976) as the '*microspinosa* group', characterised by the absence of lateral alae, somatic papillae in two incomplete rows, basic arrangement of caudal papillae four subventral, one lateral on each side. These species are *T. microspinosa* Viguerras, *T. butorides* Mollhagen, *T. eleyi* Mollhagen and *T. flchartyi*

Mollhagen. The measurements of the Australian species, and the arrangement of the somatic papillae, do not agree with any of these.

The three male worms from which the 'amended' description of *T. pelecani* were made (Johnston & Mawson 1942b) have been examined and appear to belong to *T. greeni*.

Microtetrameres pelecani (Johnston & Mawson)
FIGS 27–32

Syn. *Tetrameres pelecani* Johnston & Mawson, 1942a, p. 72; *?T. pelecani* Skrjabin, 1949.

Host and localities: *Pelecanus conspicillatus*, Brisbane, Qld.

Male: Length 6.9–8.7 mm. Buccal capsule 21–25 μm long, slightly wider dorsoventrally than from side to side. Oesophagus 1700–1900 μm long, about a quarter of the body length. In most specimens end of muscular part of oesophagus and positions of nerve ring, excretory pore and cervical papillae are not clear, but in one with oesophagus 1850 μm long, muscular oesophagus is 370 μm, nerve ring, excretory pore and cervical papillae are respectively 220 μm, 280 μm, and 270 μm from anterior end of the worm.

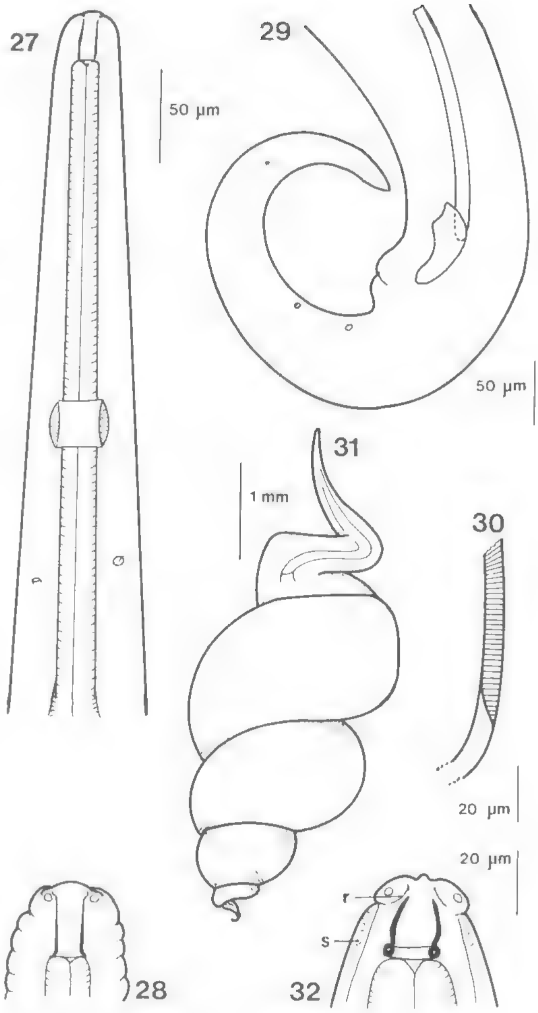
Tail 300–350 μm long, with simple rounded tip, with two pairs of papillae near cloaca and pair of phasmids at about midlength. No precloacal papillae seen. Left spicule 1350–1650 μm long with rounded tip and slight bend in proximal end, just below 60–70 um long hilt. Right spicule 150–200 μm long. Well developed guberaculum about 50–60 μm long, present in all specimens. Spicule ratio 8–9, and ratio of body length to that of left spicule 4.2–5.8.

Female: Body coiled in elongate spiral, largest ones from 4.1–5.0 mm long and 2.2–2.5 mm wide, from which anterior end projects up to 2.3 mm, but posterior end included in spiral, except for terminal 300 μm.

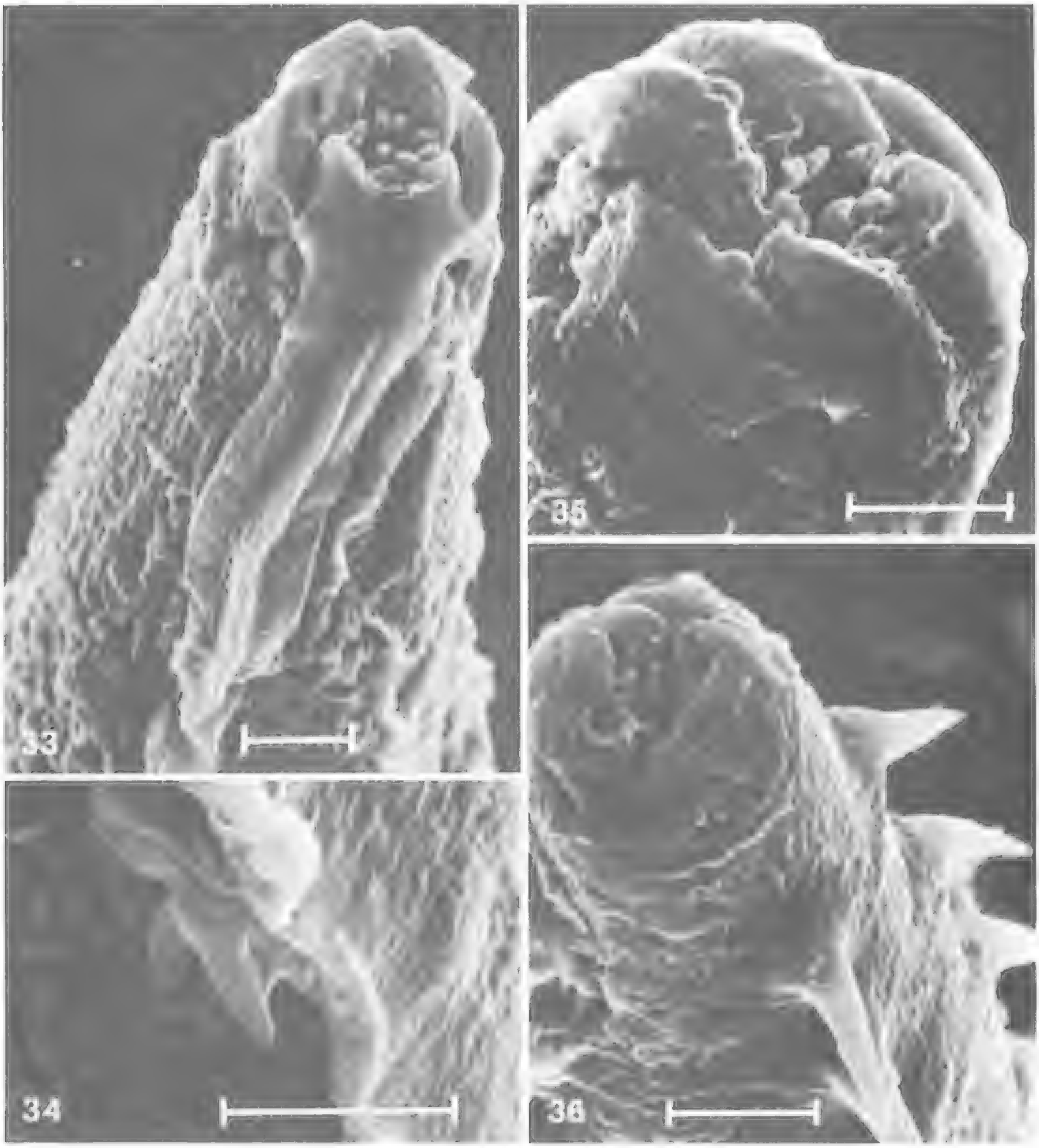
Head with trilobed lateral lips of which submedian lobes are largest. Inside of lips with thickened ridges extending from central lobe backwards onto submedian lobes (Fig. 32,r). Buccal capsule 20–25 μm long, widest near its posterior end, and ending in thickened ring. Some sclerotisation within cuticle of anterior end, behind lips, in dorsal and ventral fields Fig. 32,s). Oesophagus 2.2–2.5 mm long, muscular part 400–410 μm long, widens shortly in front of nerve ring. Nerve ring 200–230 μm from head, excretory pore near posterior end of muscular oesophagus; cervical papillae not identified with certainty.

Posterior end coiled, so position of anus and vulva obscured in most specimens. In one anus tail 300 μm, and vulva at least 1 mm from posterior end. Eggs simple, 80 x 40 μm.

The only other record of *Microtetrameres* from pelicans is that of *M. pelecani*, usually attributed to Skrjabin, 1949, from *Pelecanus onacrotalus* from Russia. This species was listed without description by Skrjabin, Schikhobalova & Sobolev (1949) as '*M. pelecani* Skrjabin'.



Figs. 27-32. *Microtetrameres pelecani*. Fig. 27. Anterior end of male. Fig. 28. Head of male. Fig. 29. Posterior end of male. Fig. 30. Hilt of left spicule. Fig. 31. Female, entire. Fig. 32. Head of female: r, internal ridges; s, sclerotization in cuticle. (Figs. 28 & 32 to same scale).



Figs 33-35. (Photomicrographs). *Tetrameres anseranas.* Fig. 33. Anterior end showing rudimentary flange, on each side of lateral ala. Fig. 34. Trifid cervical papilla beside lateral ala. Fig. 35. Head showing lips and teeth. The asymmetrically placed rounded 'warts' one on each of dorsal and ventral lips, were not seen in any other specimen, and are not considered of specific importance.
Fig. 36. *Tetrameres globosa.* Anterior end.

Skrjabin & Sobolev (1963) give description and figures of '*M. pelecani* Skrjabin, 1949', but the only reference given is that of Skrjabin *et al.* (1949). The Russian species appears to differ very little from *T. pelecani* (Johnston & Mawson 1942a), which however predates it.

Acknowledgments

I am indebted to Dr P. E. Green of the Animal Research Institute, Yeerongpilly, Qld for the material from pelicans. Other material was given by the Division of Wildlife Research,

C.S.I.R.O., Dr John Pearson of the Department of Parasitology, University of Queensland and Mrs Joan Paton, University of Adelaide. For all this help I am very grateful.

The S.E.M. photomicrographs were taken by the E.T.E.C. Autoscan in the Central Electrical Laboratory of the University of Adelaide, and I am indebted to Dr Karl Bartusek of that Laboratory for assistance.

Holotype and Allotype specimens of new species are deposited in the South Australian Museum and other type material in the Australian Helminthological Collection in the South Australian Museum.

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SALINITY TOLERANCE AND OSMOTIC BEHAVIOUR OF EUROPEAN CARP (CYPRINUS CARPIO L.) FROM THE RIVER MURRAY, AUSTRALIA

BY M. C. GEDDES

Summary

European carp from the River Murray survived direct transfer to a salinity of 12.5‰ and with acclimation, there was 50% survival at 15‰. In fresh water the carp were hyperosmotic regulators, and maintained a plasma O.P. of 247 mOsm. At salinites above 10‰ they were osmo-comformers and tolerated plasma levels up to 430 mOsm. The considerable salinity tolerance of European carp means that they will be able to survive in moderately saline waters in Australia.

SALINITY TOLERANCE AND OSMOTIC BEHAVIOUR OF EUROPEAN CARP (*CYPRINUS CARPIO* L.) FROM THE RIVER MURRAY, AUSTRALIA

by M. C. GEDDES[1]

Summary

GEDDES, M. C. (1979) Salinity tolerance and osmotic behaviour of European carp (*Cyprinus carpio* L.) from the River Murray, Australia. *Trans. R. Soc. S. Aust.* 103(7), 185-189, 31 August, 1979.

European carp from the River Murray survived direct transfer to a salinity of 12.5‰ and, with acclimation, there was 50% survival at 15‰. In fresh water the carp were hyperosmotic regulators and maintained a plasma O.P. of 247 mOsm. At salinities above 10‰ they were osmo-conformers and tolerated plasma levels up to 430 mOsm. The considerable salinity tolerance of European carp means that they will be able to survive in moderately saline waters in Australia.

Introduction

European carp (*Cyprinus carpio* L.) have been introduced into Australia on at least three different occasions (Shearer & Mulley 1978); once prior to 1865 near Sydney, then before 1903 into the Murray Irrigation Area, and into Victoria in the early 1960's. At present European carp from the latest introduction are distributed over most of the Murray-Darling and Southeast Coastal Drainage Divisions as designated in Australian Water Resources Council (1975). Shearer (1977) believes that the final range of the carp will also include the Northeast Coastal, Lake Eyre, Gulf of Carpentaria and Timor Sea Drainage Divisions. Introduction into other geographically isolated Drainage Divisions is possible, and eventually European carp may be distributed throughout Australia. In the River Murray system carp have undergone a population explosion over the last decade with annual catches in South Australia over the years 1969–70 to 1975–76 of 2000 kg, 10 000 kg, 15 000 kg, 46 000 kg, 146 000 kg, and 325 000 kg (Olsen 1977). The carp are often considered a pest because their feeding habits increase suspended solids and reduce aquatic vegetation (Shearer 1977). The present study outlines the salinity tolerance of European carp from the River Murray and describes the osmotic behaviour of carp in media of varying salinity. This information may be useful in predicting the ways in which salinity may limit distribution.

Although basically freshwater fish, cyprinodonts show considerable tolerance to water of increased salinity. Studies on the silver carp *Hypophthalmichthys molitrix* (Val.) and the grass carp *Ctenopharyngodon idella* (Val.) by Chervinski (1977) show that silver carp survive in 20% seawater (7‰) and grass carp in 25% seawater (9‰). Several species of *Cyprinodon* are listed by Deacon & Minckley (1974) as occurring at 90‰ and the Death Valley pupfish, *C. milleri*, is an osmoregulator in salinities up to 105‰ (Naiman *et al.* 1976). Several investigators have commented on the survival of *Cyprinus carpio* in water of increased salinity, and in reviewing these studies Black (1957) states that carp can live indefinitely in water of about one half seawater concentration. Al-Hamed (1971) studied salinity tolerance in *C. carpio* in Iraq and concluded that fish survived direct transfer to salinities up to 12‰ and, with acclimation, could survive in salinities as high as 17‰. Martret (1939) working on *C. carpio* in France, measured freezing point depression (△) of the blood of carp in varying salinities. He found that in freshwater △ was 0.50°C, and that the blood concentration rose to be isosmotic with the medium at △ 0.65°C, and continued up the isosmotic line to △ of 1.02°C (corresponding

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to a salinity of 19‰). Many of the studies on salinity tolerance and osmoregulation of this species have been fragmentary. They have been examined critically here and compared with results derived from carp from the River Murray.

Methods

European carp (200 g–4 kg) were caught by seine netting in the River Murray at Walkers Flat in September 1977. Small carp (<50 g) were collected by trawl net from Lake Alexandrina in December 1977. All fish were transported to the laboratory and released into aerated holding tanks. They were fed fish pellets during holding and during the experiments. Experimental media were prepared by adding seawater to de-chlorinated tapwater. Salinities were calculated from conductivity measurements using the relationship of Williams (1966) and are accurate to within ± 4%.

Direct transfer experiment: Three fish (200–250 g) were transferred to each of eight 50 l buckets containing water of 0.6‰–19‰ salinity at 19–22°C. The fish were observed each day and the survivors counted. Blood samples were taken at the termination of the experiment or, in the higher salinities, when fish became inactive. In association with this experiment two large fish (2.5 kg) were transferred from freshwater (0.6‰) to a medium of 11.5‰ while two other fish were left in freshwater as controls. Blood samples were taken at various intervals after transfer to determine the time needed for osmotic equilibrium to be re-established.

Acclimation experiments: Two acclimation experiments were conducted, one with mature fish (1.5–2.5 kg) and the other with juveniles (<50 g). The experiment with the larger fish was conducted in two cement tanks measuring 3 x 1 x 0.5 m. In the experimental tank five fish were subjected to increasing salinity while in the control tank three fish were kept in freshwater. At approximately six-day intervals the survivors were counted, blood samples taken, and the salinity in the experimental tank increased. The experiment was run for 38 days and the temperature range was 16–21°C. The experiment with juvenile fish was conducted in two aquaria. The experimental aquarium contained six fish subjected to increased salinity at approximately eight-day intervals; the control aquarium contained six fish in freshwater. No blood samples were taken from these small fish. Temperature range was 18–24°C.

Blood sampling and determination of osmotic pressure: A 0.2 ml blood sample was collected from the caudal artery using a heparinised 1 ml syringe and a 21 g needle. Blood was stored in ice and centrifuged at 3000 rpm for 15 minutes soon after collection. The osmotic pressure of the plasma was measured immediately after centrifugation using a Knauer Semi-Micro Osmometer. Each determination required 50 μl of plasma. Duplicates were determined for some samples and were accurate to within 1%.

Results

Table 1 shows that all carp survived direct transfer to 12.5‰, while only one survived for six days at 14‰. No fish survived above 18‰ (Table 2). The initial mortalities in the experiments were at 13.3‰ and 13.1‰ for the mature fish and juvenile fish respectively, whereas 50% mortality occurred at approximately 15‰ and 16‰ respectively. There were no mortalities in either control.

Figure 1 shows the change with time of the osmotic pressure (O.P.) of the plasma of carp transferred from 0.6‰ (20 mOsm/Kg H_2O) to 11.6‰ (351 mOsm/Kg H_2O). The O.P. rose quickly in the initial 24 hours and then rose more gradually until it reached a new equilibrium; after approximately eight days the plasma was isosmotic with the medium. The O.P. of the control fish fell slightly during the experiment probably as a result of the repeated removal of blood.

Determinations of O.P. are shown in Figure 2 and Table 3. In freshwater the carp are hyper-osmotic regulators with a blood O.P. of 247 mOsm/Kg H_2O. As salinity increases the blood O.P. is maintained until about 200 mOsm and then rises gradually until it is isos-

TABLE 1

Survival of Cyprinus carpio *after direct transfer to media of various salinities.*

Salinity (‰)	Number transferred	Survivors after 3 days	Survivors after 6 days
0.6	3	3	3
6.2	3	3	3
8.0	3	3	3
10.4	3	3	3
12.5	3	3	3
14.0	3	2	1
16.8	3	0	0
19.0	3	0	0

motic with the medium at about 300 mOsm. The blood O.P. then follows the isosmotic line. The two points below the isosmotic line represent fish that had insufficient time to acclimate to media of increased O.P. These fish died soon after the blood sample was taken. It appears that carp are unable to survive with a blood O.P. in excess of about 430 mOsm.

TABLE 2

Survival of juvenile and mature Cyprinus carpio *with acclimation to inceasing salinity using groups of 5 experimental and 3 control mature fish and 6 experimental and 6 control juvenile fish.*

Salinity (‰)	Days of exposure	Survivors in experimental container	Survivors in control container
(i) Mature fish (1.5-2.5 kg)			
0.6	6	5	3
5.6	6	5	3
10.8	6	5	3
13.3	6	4	3
14.3	5	3	3
15.8	6	1	3
18.7	3	0	3
(ii) Juvenile fish <50 g			
0.6	5	6	6
6.2	7	6	6
8.4	8	6	6
11.2	6	6	6
13.1	10	5	6
16.2	8	3	6
18.2	3	0	6

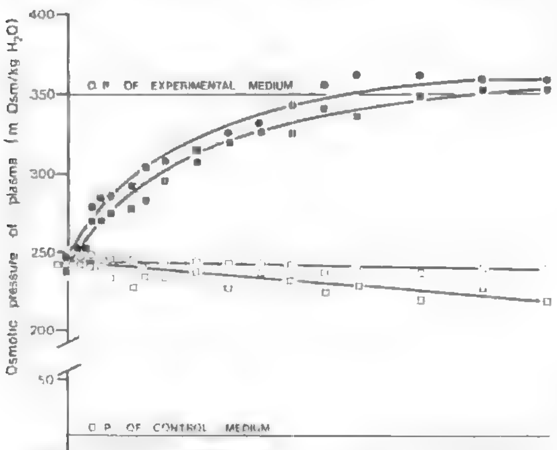

Fig. 1. Changes in osmotic pressure of the plasma of *Cyprinus carpio* after transfer from freshwater to water of 350 mOsm. ● and ■ show O.P. of fish after transfer to 350 mOsm; ○ and □ show O.P. of fish maintained in freshwater.

TABLE 3

Osmotic pressure of the plasma of Cyprinus carpio *acclimated to various salinities.*

Salinity (‰)	O.P. medium ($mOsm/Kg\ H_2O$)	O.P. plasma ($mOsm/Kg\ H_2O$) mean	S.D.	Number of fish
0.6	20	247	±5	10
5.6	168	252	±6	5
6.2	190	250	±4	3
8.0	242	270	±10	3
10.4	315	320	±9	3
10.8	330	335	±7	5
11.6	352	356		2
12.5	377	370	±8	3
13.3	398	395	±4	4
14.0	425	404*		2
14.3	430	427	±5	3
16.8	512	432†		1

* determined only two days after transfer to medium
† determined only one day after transfer to medium

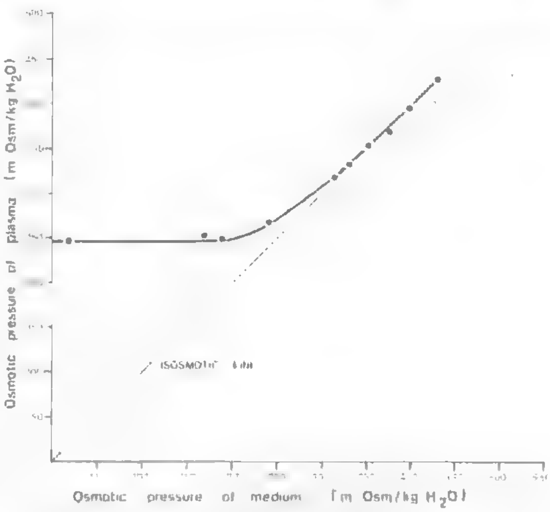

Fig. 2. Osmotic pressure of plasma of *Cyprinus carpio* in various media. ○ determined only two days after transfer to medium; □ determined only one day after transfer to medium. All other points determined six or more days after transfer.

Discussion

Mature and juvenile *Cyprinus carpio* from the River Murray showed considerable tolerance to increased salinity. They survived direct transfer to dilute seawater of 12.5‰ and, with acclimation, the salinity tolerance was raised to about 15‰. Martret (1939) stated that carp shows signs of distress at △ 0.9°C (approx. 17‰ and Al-Hamed (1971) showed that 70% of carp survived direct transfer to 12‰ and with acclimation there was 100% survival at 16‰, 80% at 17‰ and no survival at 17.5‰. In the present study dilutions of seawater,

having ionic proportions similar to those found in most Australian inland saline waters and in estuaries, were used as experimental media. Although Martret used solutions of NaCl as experimental media and Al-Hamed used experimental media of unknown ionic proportions, the salinity tolerances reported are very similar to those of the present study. It appears that *C. carpio* tolerates higher salinities than do silver carp, *Hypophthalmichthys molitrix* (7‰), and grass carp, *Ctenopharyngodon idella* (9‰) (Chervinski 1977).

Carp are hyperosomotic regulators in fresh water with a blood O.P. of 247 mOsm. This blood O.P. is maintained until the external O.P. increases to 200 mOsm and then rises gradually, so that the fish are isosmotic with the medium at about 300 mOsm. At higher salinities carp are osmoconformers tolerating increased O.P. of the blood. It appears that blood O.P. in excess of 430 mOsm is intolerable to the cells and so the fish die. Martret (1939) and Leorey (1938) (in Black 1957) have measured the O.P. of *C. carpio* in fresh water as 263 and 285 mOsm respectively. Martret measured the isosmotic point at 350 mOsm and the maximum blood O.P. at 480 mOsm. These values are somewhat higher than those here, possibly reflecting differences related to the differences in ionic proportions of the experimental media, osmotic behaviours of fish from different populations, acclimation, or in the methods of measuring O.P. The degree of tolerance to increased blood O.P. shown by *C. carpio* may be compared to that of the halophilic species of *Cyprinodon* such as *C. milleri*. That species survives over the range fresh water to 105‰ by regulating the O.P. of the blood so that blood O.P. rises from 293 mOsm to 503 mOsm while external O.P. rises from 10 to 3000 mOsm (Naiman *et al.* 1976). The upper level of blood O.P. and the percentage increase tolerated, 175% for *Cyprinus carpio* and 172% for *Cyprinodon milleri*, are similar for the two species.

This study shows that *C. carpio* is able to enter moderately saline waters in Australia, perhaps up to 15‰. Al-Hamed (1971) has shown that eggs of *C. carpio* develop and hatch successfully in salinities up to 6.6‰ and so breeding populations may be established in some saline waters. In South Australia, European carp may extend their range into the Lake Eyre drainage basin where many waters are slightly saline and the fish fauna is characterized by tolerance to increased salinities (Glover & Sim 1978). Waters of increased salinity along the River Murray including lakes (such as L. Bonney), billabongs and drainage disposal sites (Engineering and Water Supply Department 1978) will be suitable habitats for European carp. In the Coorong lagoon south of the Murray mouth a salinity gradient from fresh water to sea water exists and the considerable salinity tolerance of European carp may allow their partial establishment there.

Although European carp are considered a freshwater fish they show considerable tolerance to increase salinity and this, together with their tolerance to other environmental factors such as temperature and oxygen concentration, means that carp can colonise most waters throughout Australia. Much more work needs to be done on factors which may limit distribution of European carp in Australia and their ecological consequences.

Acknowledgments

I wish to acknowledge the technical assistance of Lesley Hurley, Bridget Bonnin and Julie Diener. Thanks are due to Mr B. D. Mitchell for help in collecting and holding the carp and to Dr K. F. Walker for critically reading the manuscript.

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RECOGNITION OF PTEROTHAMNION NAEGELI WITH TAXONOMIC NOTES ON P. SIMILE (HOOKER & HARVEY) NAEGELI AND PLATYTHAMNION NODIFERUM (J. AGARDH) WOLLASTON (RHODOPHYTA, CERAMIACEAE)

BY ELISE M. WOLLASTON

Summary

The plant presently referred to Antithamnion simile (Hooker & Harvey) J. Agardh is here replaced in Pterothamnion Naegli as P. simile, a transfer first established by Naegeli (1861). This genus shows a thallus branching pattern similar to that of Platyhamnion but regularly bears only two opposite whorl-branchlets from each axial cell. The relationship of these two genera is discussed. Harvey (1855, 1862, 1863) also recognized plants now accepted as Platyhamnion nodiferum (J. Agardh) Wollaston from the west and south coasts of Australia as Callithamnion simile (=Antithamnion simile) and hence the taxonomic position of P. nodiferum is also discussed.

RECOGNITION OF *PTEROTHAMNION* NAEGELI WITH TAXONOMIC NOTES ON *P. SIMILE* (HOOKER & HARVEY) NAEGELI AND *PLATYTHAMNION NODIFERUM* (J. AGARDH) WOLLASTON (RHODOPHYTA, CERAMIACEAE)

by ELISE M. WOLLASTON[1]

Summary

WOLLASTON, E. M. (1979) Recognition of *Pterothamnion* Naegeli with taxonomic notes on *P. simile* (Hooker & Harvey) Naegeli and *Platythamnion nodiferum* (J. Agardh) Wollaston (Rhodophyta, Ceramiaceae) *Trans. R. Soc. S. Aust.* **103**(8), 191-196, 30 November, 1979.

The plant presently referred to *Antithamnion simile* (Hooker & Harvey) J. Agardh is here replaced in *Pterothamnion* Naegeli as *P. simile*, a transfer first established by Naegeli (1861). This genus shows a thallus branching pattern similar to that of *Platythamnion* but regularly bears only two opposite whorl-branchlets from each axial cell. The relationship of these two genera is discussed. Harvey (1855, 1862, 1863) also recognized plants now accepted as *Platythamnion nodiferum* (J. Agardh) Wollaston from the west and south coasts of Australia as *Callithamnion simile* (=*Antithamnion simile*) and hence the taxonomic position of *P. nodiferum* is also discussed

Introduction

Callithamnion simile Hooker & Harvey (1845) was based upon plants collected by Hooker from Christmas Harbour, Kerguelen's Land, in 1840. Later Harvey (1855, 1862, 1863, Alg. Aust. Exsicc., 543) included plants from the west and south coasts of Australia under this epithet. However J. Agardh (1876) separated the Australian plants from *C. simile* and recognized them as *C. plumula* var. *investiens* (based on Alg. Aust. Exsicc. 543a, New Holland) and *C. nodiferum* (based on Alg. Aust. Exsicc., 543D, Port Fairy, Vic.). Type material for both taxa has been examined; the former is recognized as *Antithamnion armatum* (J. Agardh) De Toni (1903), and the latter as *Platythamnion nodiferum* (J. Agardh) Wollaston (1968). This species develops a much more robust thallus than is known for congeners and hence it's identity is discussed in relation to features characteristic of the genus.

Type collections of *Callithamnion simile* from Kerguelen's Land have been examined and the plant found to correspond in morphological features with *Pterothamnion* described by Naegeli (1855) for *P. plumula* and *P. floccosum* (now recognized as *Antithamnion plumula* and *A. floccosum* respectively). Naegeli (1861) recognized differences between *Pterothamnion plumula*, the type species of the genus, and *P. floccosum* and described the subgenera *Eupterothamnion* and *Haplocladium* to accommodate the two taxa. He also included several species of *Callithamnion* in *Pterothamnion*, subgenus *Eupterothamnion*, including *C. simile* from Kerguelen's Land. Later, however, J. Agardh (1892) transferred this latter species to *Antithamnion*.

This study examines the relationships of *Pterothamnion* and *Platythamnion*, replaces *Antithamnion* (*Callithamnion*) *simile* in the former genus as *Pterothamnion simile*, and accepts *Platythamnion nodiferum* as a species of *Platythamnion*.

Pterothamnion simile (Hooker & Harvey) Naegeli 1861: 376.

(FIGS 1-4)

Callithamnion simile Hooker & Harvey 1845: 271. J. Agardh 1851: 30; 1876: 24. Askenasy 1888: 34, pl. 8, figs 3-9. Dickie 1876: 202; 1879: 62. Hemsley 1884: 242. Hooker 1847: 489. Kuetzing 1849: 648; 1861: 26, pl. 82, fig. 2.

Antithamnion simile (Hooker & Harvey) J. Agardh 1892: 20; 1896, Index p. I. De Toni

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Fig. 1. Lectotype of *Callithamnion simile* (Christmas Harbour, Kerguelen's Land, *J. D. Hooker,* July 1840) in BM.

1903: 1399. Papenfuss 1964: 46. Reinbold 1907: 575. Skottsberg 1953: 563, fig. 23.

Callithamnion pinastroides var. *ramulosum* Reinsch 1888: 155; 1890: 375.

Antithamnion ramulosum (Reinsch) Kylin *in* Kylin & Skottsberg 1919: 70, fig. 35.

Thallus to 6 cm high consisting of branched, uncorticated, distichous axes which appear annular (Fig. 1) and bear two opposite whorl-branchlets from each axial cell (Figs 2, 3). Whorl-branchlets either unbranched (usually those of the immature upper thallus) or bearing a series of adaxial branchlets which may themselves bear short abaxial branchlets (Figs 2, 3); usually reduced in length and branching towards base of thallus. Indeterminate lateral branches alternate replacing whorl-branchlets and distichously placed at regular intervals of 4–5 axial cells; when young curved over the growing apex of each axis (Fig. 2) as in *Platythamnion.* Axial cells bearing lateral branches occasionally developing 1(–2) additional short, simple whorl-branchlet(s) at right angles to plane of thallus branching (Fig. 3). Gland cells prominent, cut off laterally from whorl-branchlet cells of either adaxial branchlets or, more typically, rachides near the outer tips; several gland cells may occur in series from adjacent cells (Figs 2, 3) as well illustrated by Kylin & Skottsberg (1919, Fig. 35) for *Antithamnion ramulosum.* Reproductive structures not observed in detail, although several, apparently tetrahedrally divided tetrasporangia were found on one of Hooker's plants (Fig. 4). Askenasy (1888, pl. 8, Fig. 4) illustrates rounded groups of carposporangia and indicates that the carposporophyte develops on the basal cell of an elongate whorl-branchlet and that the axes of the fertile branches may also continue to elongate as occurs in *Scagelia* (Wollaston 1971a) and sometimes in *Platythamnion* (Wollaston 1972).

Type locality: Christmas Harbour, Kerguelen's Land (*J. D. Hooker,* July 1840).

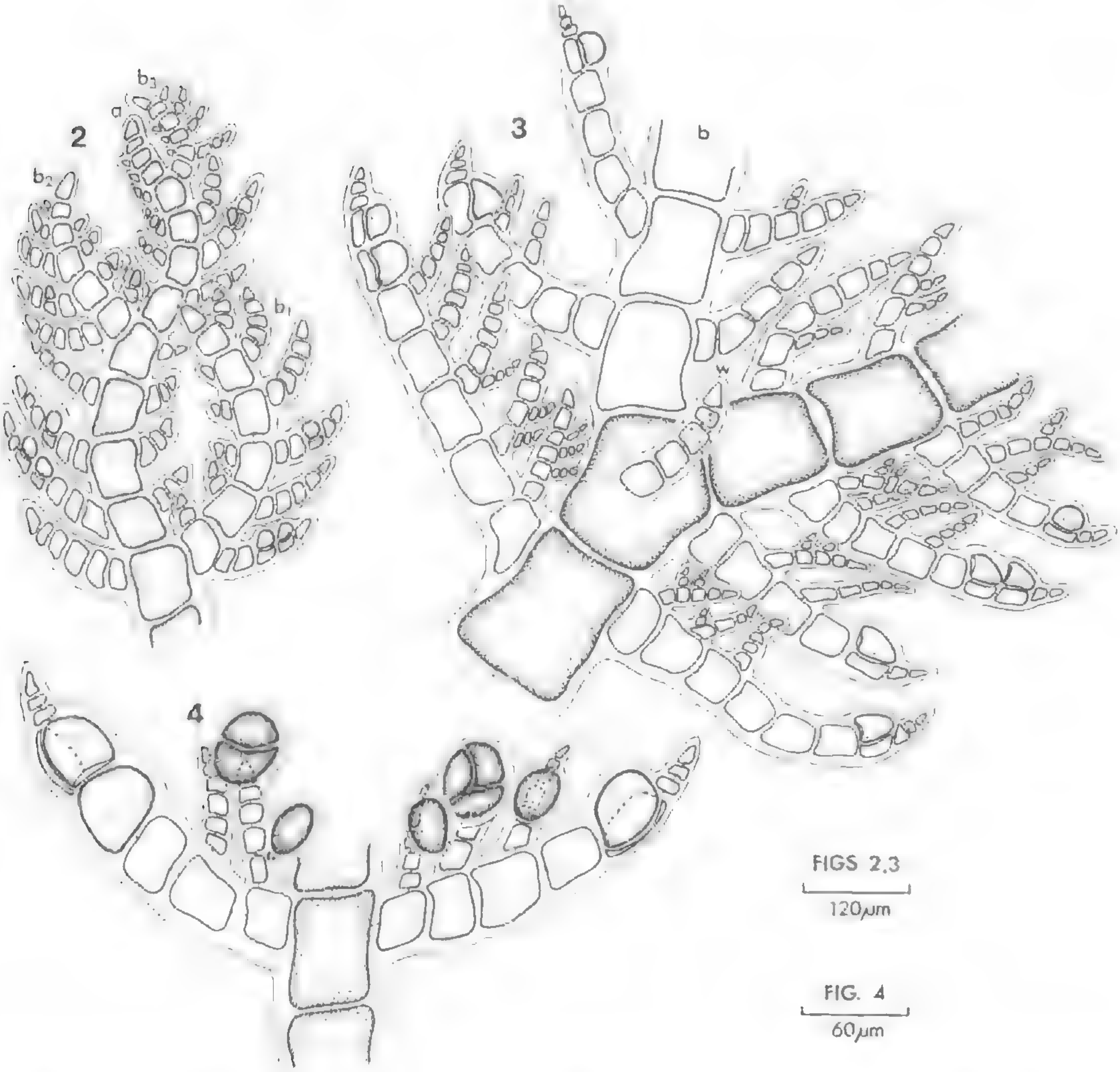
Lectotype: Herb. British Museum (Natural History).

Distribution: Kerguelen I., South Georgia, Enderby Land.

The morphology of *Pterothamnion simile* has also been well documented by Dickie (1879, as *Callithamnion simile*), Askenasy (1888, as *C. simile*), Kylin (*in* Kylin & Skottsberg 1919, as *Antithamnion ramulosum*) and by Skottsberg (1953, as *A. simile*). The present description of thallus structure is based on collections of *Callithamnion simile* from Kerguelen's Land, including specimens from the type collection which have recently been examined. These specimens are in good condition and thallus features are readily observed.

Naegeli (1855) described *Pterothamnion* for distichously-branched plants having alternate, indeterminate lateral branches initiated at near-regular intervals (2–6 axial cells apart) and with two opposite whorl-branchlets either simple or adaxially branched from each axial cell. At that time he included *Callithamnion plumula* and *C. floccosum* in his new genus. Cramer's excellent figures (*in* Naegeli, 1855) clearly illustrate features characteristic of *Pterothamnion* including details such as the development of an additional whorl-branchlet on axial cells bearing lateral branches, as is sometimes seen in *P. simile.*

On the basis of the above features it is clear that the plant first described as *Callithamnion simile* belongs to the genus *Ptero-*



Figs 2-4 *Callithamnion simile* H. & H. Fig. 2 Branch apex showing distichous arrangement of opposite whorl-branchlets and lateral branches (b1-b3) arising in place of whorl-branchlets from each 4th axial cell and with the youngest branch (b3) curved over the axial apex (a). Fig. 3 Central thallus showing mature adaxially-branched whorl-branchlets; one whorl-branchlet (w) of a second pair borne on the axial cell which also bears the lateral branch (b); prominent gland cells near tips of whorl-branchlets. Fig. 4 Whorl-branchlets showing several stages in development of tetrasporangia borne from the adaxial branches, and gland cells near whorl-branchlet tips.

thamnion, as indicated by Naegeli (1861), and should be recognized as *P. simile*.

Naegeli (1861) extended *Pterothamnion* (subgenus *Eupterothamnion*) to include plants having whorls of more than two whorl-branchlets arranged so that the two (opposite) first-formed whorl-branchlets lay in the plane of thallus branching. Plants of this form, bearing whorls of two opposite major and two minor whorl-branchlets, were later referred to a new genus, *Platythamnion* (J. Agardh 1892). Similarly plants bearing whorls of four equal whorl-branchlets have, on the basis of various combinations of features, been segregated into other genera. *Pterothamnion* is thus maintained for plants which normally develop one pair of opposite whorl-branchlets per axial cell, as described by Naegeli (1855).

Pterothamnion appears to be closely related to *Platythamnion* as indicated by similar development of a regular alternately branched thallus. However, in *Pterothamnion* axial cells develop only one pair of whorl-branchlets per cell and whorl-branchlets are often reduced in form towards the base of the thallus; at branch apices whorl-branchlets usually remain simple and unbranched until near mature in length. In *Platythamnion,* however, each axial cell bears two pairs of whorl-branchlets, branching of whorl-branchlets is increased in the lower thallus and whorl-branchlet branches are initiated at an early stage when rachides are only a few cells long. Also in several species of *Platythamnion,* mature whorl-branchlets bear opposite (e.g. *P. heteromorphum, P. reversum*) or tristichous (e.g. *P. villosum*) branches whilst, as far as is known, whorl-branchlets of *Pterothamnion* are always simple or adaxially branched. These features suggest that *Pterothamnion* represents a plant form closely allied to *Platythamnion* but in which whorl-branchlet development is restricted both in number of whorl-branchlets produced and in the branching pattern of individual whorl-branchlets. Further observations of fresh material and a study of reproductive details is necessary to confirm the relationships of *Pterothamnion.*

Naegeli (1861) referred to the similarity of *Sporocanthus* Kuetzing to *Pterothamnion.* However, neither Kuetzing's drawings nor description are sufficiently clear to certainly identify the plant and no material has been available for checking. Skottsberg (1953) considered that *Antithamnion minutissimum* Levring was the "nearest relative" of *Pterothamnion simile.* However Levring (1941) described *A. minutissimum* as a much smaller plant, to 4 mm high, and gland cells in Levring's figures are scattered on whorl-branchlets and not shown in series near the tips of rachides such as frequently occurs in *P. simile.* However, Levring's plant resembles *P. simile* in bearing opposite, secundly-branched whorl-branchlets, and his figures indicate that carposporophytes, like those shown by Askenasy for *P. simile,* develop from the basal cells of elongated whorl-branchlets and that fertile axes continue to elongate after carposporophyte initiation.

Another species, *Antithamnion antarcticum* Kylin, also bears opposite whorl-branchlets like those characteristic of *Pterothamnion.* However, neither the original description and illustrations given by Kylin (*in* Kylin & Skottsberg 1919) nor those of Lamb & Zimmermann (1977) are adequate to confirm generic identity. Further examination of both *A. minutissimum* and *A. antarcticum* is necessary to determine the taxonomic placement of these taxa.

A note on the taxonomic position of Platythamnion nodiferum (J.Ag.) Wollaston

Platythamnion nodiferum was transferred from *Antithamnion* to *Platythamnion* by Wollaston (1968) who gave a detailed description of the plant habit and reproduction. *Platythamnion* is distinguished by a combination of features including whorl-branchlets arranged in whorls of four (two major, which are adaxially branched in most species, and two minor), a regular alternate pattern of lateral branch development and gland cells cut off laterally from whorl-branchlet cells. In these features *P. nodiferum* is similar to congeners. It is however a much larger plant [to 20 cm in contrast to a maximum of 6(–8) cm recorded for other species] with mature axes densely corticated with rhizoids and bearing minor whorl-branchlets which are much less reduced than are those in other species. As they become older, the minor whorl-branchlets bear an increasing number of adaxial branches and in older parts of the thallus they appear equivalent in form to the major whorl-branchlets. Similarity of major and minor whorl-branchlets near the base of the thallus also occurs in *P. recurvatum* Wollaston and in *P. villosum* Kylin, but in the latter is due to the loss of the outer part of the rachides of the major whorl-branchlets (Wollaston 1972).

Rhizoidal cortication of axes in *P. nodiferum* is possibly associated with the large thallus developed in this species. Wollaston (1968) observed that in this and closely related tribes of Ceramiaceae rhizoidal cortication was present in species developing "comparatively large thalli".

In reproductive detail *P. nodiferum* resembles congeners; however, it develops a series of up to 20 carpogonial branches at each fertile branch tip whereas other species, from the Pacific coast of North America and from Japan, produce a maximum of only 3–4 carpogonial branches and in some species no more than one has been observed. Unfortunately carpogonial branch development has not been observed in *P. cuspidatum* or *P. francisianum* recently described from southern Australia (Wollaston 1978).

It is of interest to note that a similar contrast exists in *Antithamnion* in that species recorded from western North America produce only 2-6 carpogonial branches on each fertile branch tip whereas Australian species again develop up to 20 (Wollaston 1971b).

Platythamnion cuspidatum and *P. francisianum* are much smaller plants (to 2 cm) than *P. nodiferum* and closely resemble non-Australian congeners. In both these species, axes are uncorticated and major and minor whorl-branchlets are distinctly different in length and form (Wollaston 1978). *P. nodiferum* with its robust form and variant morphology, cannot be accepted as a geographically isolated species from the southern hemisphere unless it can be shown that both *P. cuspidatum* and *P. francisianum* have been introduced to this region. This however seems unlikely since both species are clearly distinct from previously-described northern hemisphere species.

Platythamnion nodiferum is common along the southern coast of Australia and at least for the present must be regarded as an unusually robust and thriving species of this genus.

Acknowledgments

I am grateful to those who have provided study material and especially for Herbarium loans from the British Museum of Natural History, the Botanical Museum, Lund, and Trinity College, Dublin. I also gratefully acknowledge technical assistance provided through the Australian Research Grants Committee.

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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE BILLY CREEK FORMATION (CAMBRIAN), CENTRAL AND NORTHERN FLINDERS RANGES, SOUTH AUSTRALIA

BY P. S. MOORE

Summary

With the exception of Reaphook Hill, surface outcrops of the Billy Creek Formation comprise three distinctive lithological units, herein termed the Warragee Member, the Nildottie Siltstone Member and the Eregunda Sandstone Member. The Warragee Member is the basal unit and comprises variegated, fine grained siltstone and shale with minor, thin dolomitic interbeds. The overlying Nildottie Siltstone Member is coarser-grained, and contains an abundance of ripple marks, halite casts and desiccation cracks. Carbonates and non-red clastics are absent. The Eregunda Sandstone Member is the uppermost unit of the Billy Creek Formation in the central and northern Flinders Ranges. It comprises a sequence of fine-grained, current lineated and cross-stratified, greyish red arkose, with minor interbedded shale and siltstone. The entire sequence is interpreted as a shallow water, marginal marine to paralic deposit, which spread over the Adelaide 'Geosyncline' in response to tectonic uplift (the Kangarooian Movements) mainly in the south and southeast.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE BILLY CREEK FORMATION (CAMBRIAN), CENTRAL AND NORTHERN FLINDERS RANGES, SOUTH AUSTRALIA

by P. S. MOORE*

Summary

MOORE, P. S. (1979) Stratigraphy and depositional environments of the Billy Creek Formation (Cambrian), central and northern Flinders Ranges, South Australia. *Trans. R. Soc. S. Aust.* **103**(8), 197-211, 30 November, 1979.

With the exception of Reaphook Hill, surface outcrops of the Billy Creek Formation comprise three distinctive lithological units, herein termed the Warragee Member, the Nildottie Siltstone Member and the Eregunda Sandstone Member. The Warragee Member is the basal unit and comprises variegated, fine grained siltstone and shale with minor, thin dolomitic interbeds. The overlying Nildottie Siltstone Member is coarser-grained, and contains an abundance of ripple marks, halite casts and desiccation cracks. Carbonates and non-red clastics are absent. The Eregunda Sandstone Member is the uppermost unit of the Billy Creek Formation in the central and northern Flinders Ranges. It comprises a sequence of fine-grained, current lineated and cross-stratified, greyish red arkose, with minor interbedded shale and siltstone. The entire sequence is interpreted as a shallow water, marginal marine to paralic deposit, which spread over the Adelaide 'Geosyncline' in response to tectonic uplift (the Kangarooian Movements) mainly in the south and southeast.

Introduction

The Billy Creek Formation outcrops sporadically throughout the central and northern Flinders Ranges and at Reaphook Hill, approximately 50 km to the east (Fig. 1). It has also been identified in the subsurface of the Lake Frome region (Daily 1968[1]; Youngs 1978). The formation comprises a Lower to Middle Cambrian red-bed sequence of shale, siltstone and sandstone with minor limestone, dolomite and tuff. Non-red clastics are uncommon and occur mainly in the lower portions of the sequence. Maximum recorded thickness is slightly in excess of 900 m.

The first direct reference to the sequence now defined as the Billy Creek Formation was by Howchin (1907), who suggested that the red-beds were dominantly subaerial deposits. Mawson (1939) also reported on the sequence, and presented two stratigraphic sections describing outcrops in the Wirrealpa Basin[2]. The Billy Creek Formation was finally named and a type section defined by Daily (1956). Daily's type section, located approximately 2.5 km north of Ten Mile Creek, is in a similar position to Mawson's (1939) traverse. Daily (1956) described the Billy Creek Formation at this locality as a sequence of red-beds 3300 feet (approx. 1000 m) thick, conformably overlying the Oraparinna Shale. He continued: 'It consists dominantly of chocolate coloured micaceous shales, sandstones and siltstones. The shales occupy most of the thickness and are often ripple marked. Pseudomorphs after halite occur in the shales in the upper parts of the formation. Thin buff coloured dolomites and calcareous shales are common in the lower 1200 feet'.

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[1] Daily, B. (1968) Remarks on the subsurface stratigraphy and palaeontology of the Delhi-Santos Lake Frome Nos. 1-3 stratigraphic wells. *In* Delhi Australian Petroleum Ltd., and Santos Ltd. (1968) Well completion report, Lake Frome 1, 2, 3, S. Aust, Dept Mines open file Env. 968 (unpublished)

[2] The Wirrealpa Basin constitutes a tectonic basin formed during Delamerian folding, which occurs in the area adjacent to and south of the Wirrealpa Homestead. The term was first used by Mawson (1939) while describing a thick sequence of Cambrian strata which outcrops in the basin.

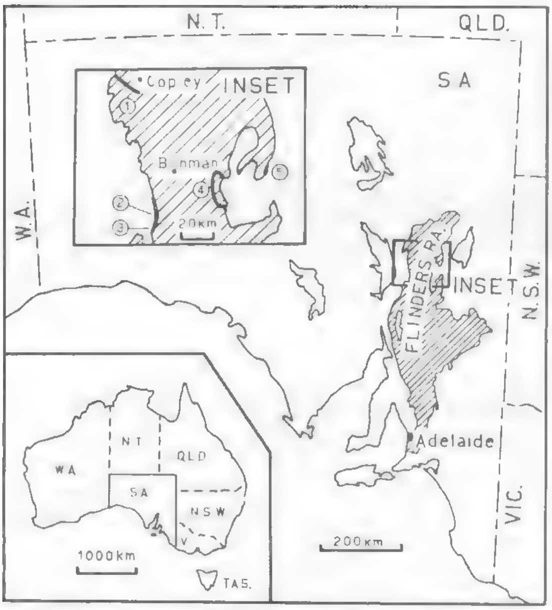


Fig. 1. Location map showing outcrops of the Billy Creek Formation discussed in detail and divided into members in this publication: Mount Scott Range (locality 1), Brachina (2) and Bunyeroo (3) in the Heysen Range, Wirrealpa Basin (4), and Chambers Gorge/Mt Frome (5).

In a summary of the environment of deposition of the Billy Creek Formation, Dalgarno (1964) stated that 'the red argillites of the Billy Creek Formation appear to represent a mud flat environment with occasional incursions of the sea, indicating regression with large supplies of fine terrigenous clastics. Very small scale oscillation ripple marks, halite pseudomorphs and raindrop impressions are environmental indicators. The last phase of deposition in this unit is more arenaceous with cross-bedding, suggesting a deltaic environment. Thin tuffaceous bands in the lower part of the formation may be related to vulcanism in the province to the east'. Daily (1976) supported this general environmental interpretation, and suggested that 'a paralic environment is envisaged, mainly regressive to restrictive with evaporitic conditions favouring red-bed formation under oxidising conditions. A marine influence is shown by rare trilobite occurrences in green shale and shallow-water, foetid limestone and carbonate-rich tuff'.

For all outcrops with the exception of Reaphook Hill, this study divides the Billy Creek Formation into three members, herein termed the Warragee Member, the Nildottie Siltstone Member and the Eregunda Sandstone Member (Fig. 2). The Reaphook Hill sequence is rather complex and individual in character, and is not discussed in this publication. The Edeowie Limestone Memeber, which Dalgarno & Johnson (1962) defined as the basal member of the Billy Creek Formation, has been redefined as part of the Oraparinna Shale (Moore 1979).

Dalgarno (1964) subdivided the Billy Creek Formation into two parts. His 'lower member' comprised 'alternating red and grey-green silts with minor sandy bands and thin dolomitic beds' (Dalgarno 1964) and corresponds essentially to the Warragee Member as defined herein. Dalgarno (1964) described the uppermost units of the Billy Creek Formation as "red brown micaceous sandstones very similar in character to the Moodlatana Formation". However, the lower part of this red-brown sequence comprises dominantly coarse siltstone, and thus two members are recognised by the author; the (lower) Nildottie Siltstone Member and the (upper) Eregunda Sandstone Member.

Stratigraphy of the Warragee Member

Introduction

Throughout the central Flinders Ranges and in the Mount Scott Range, the lower portion of the Billy Creek Formation is dominated by red, green and grey shale and fine to medium siltstone. Minor interbeds of dolomite, dolomitic limestone, tuff and coarse siltstone are also present. The sequence is herein termed the Warragee Member. The name is derived from the Warragee Bore, located approximately 20 km northwest of the Wirrealpa homestead, in the Wirrealpa Basin. The type section (Section BC–B, Figs. 2, 3, 4 and 5a) is located in an area of undulatory topography, 2.5 km north of the Ten Mile Creek. The section corresponds with the basal 350 m of Daily's (1956) type section of the Billy Creek Formation.

Outcrop of the Warragee Member and locations of principal measured sections are shown in Fig. 2. The member attains its maximum measured thickness of 371 m in Section BU–A, south of the Bunyeroo Gorge, and becomes progressively thinner towards the north and northeast. It is absent from outcrops immediately south of the Ten Mile Creek graben (Section BC–F3, Fig. 2), although this may be due in part to faulting.

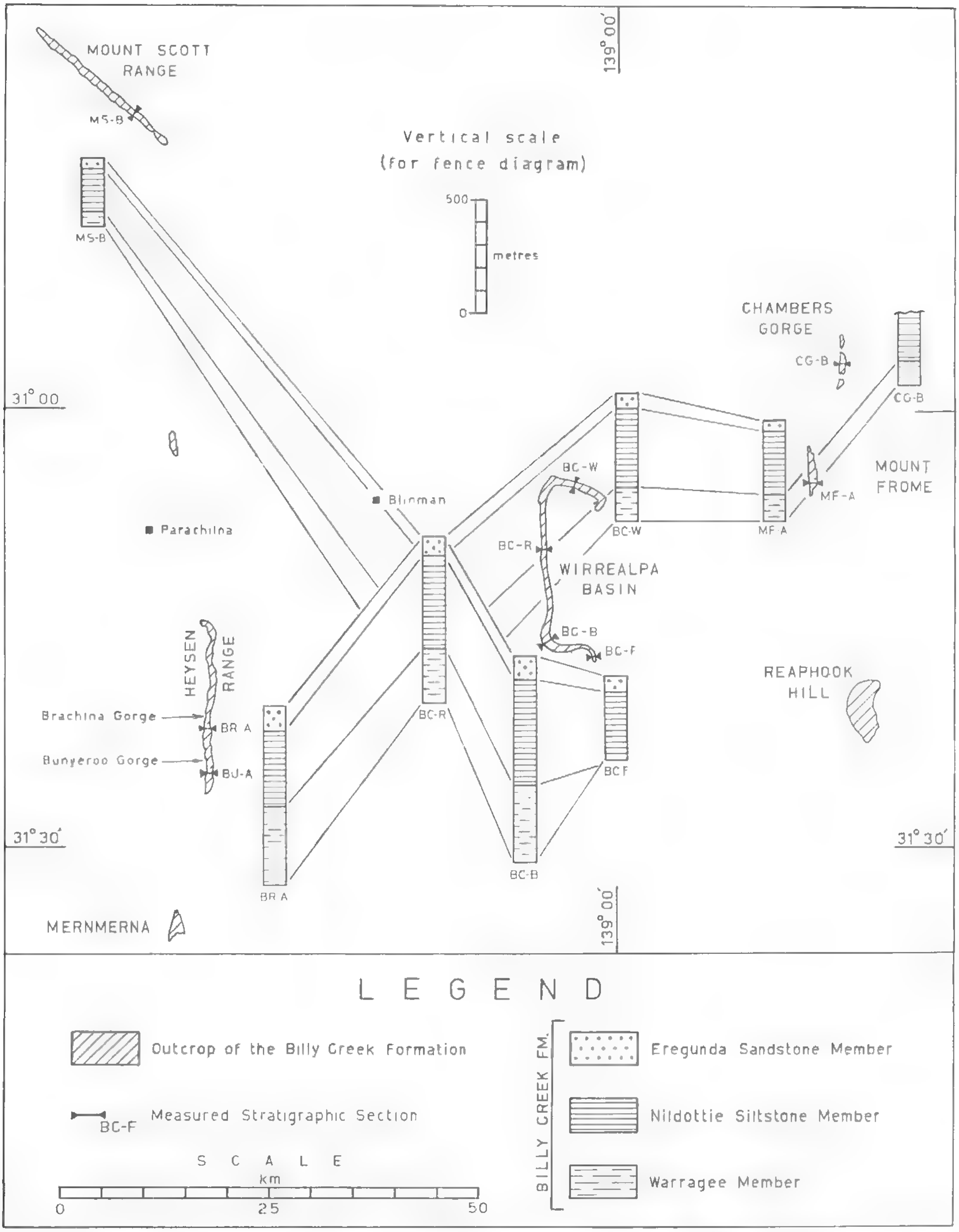


Fig. 2. Combined outcrop map and fence diagram for outcrops of the Billy Creek Formation in the central and northern Flinders Ranges.

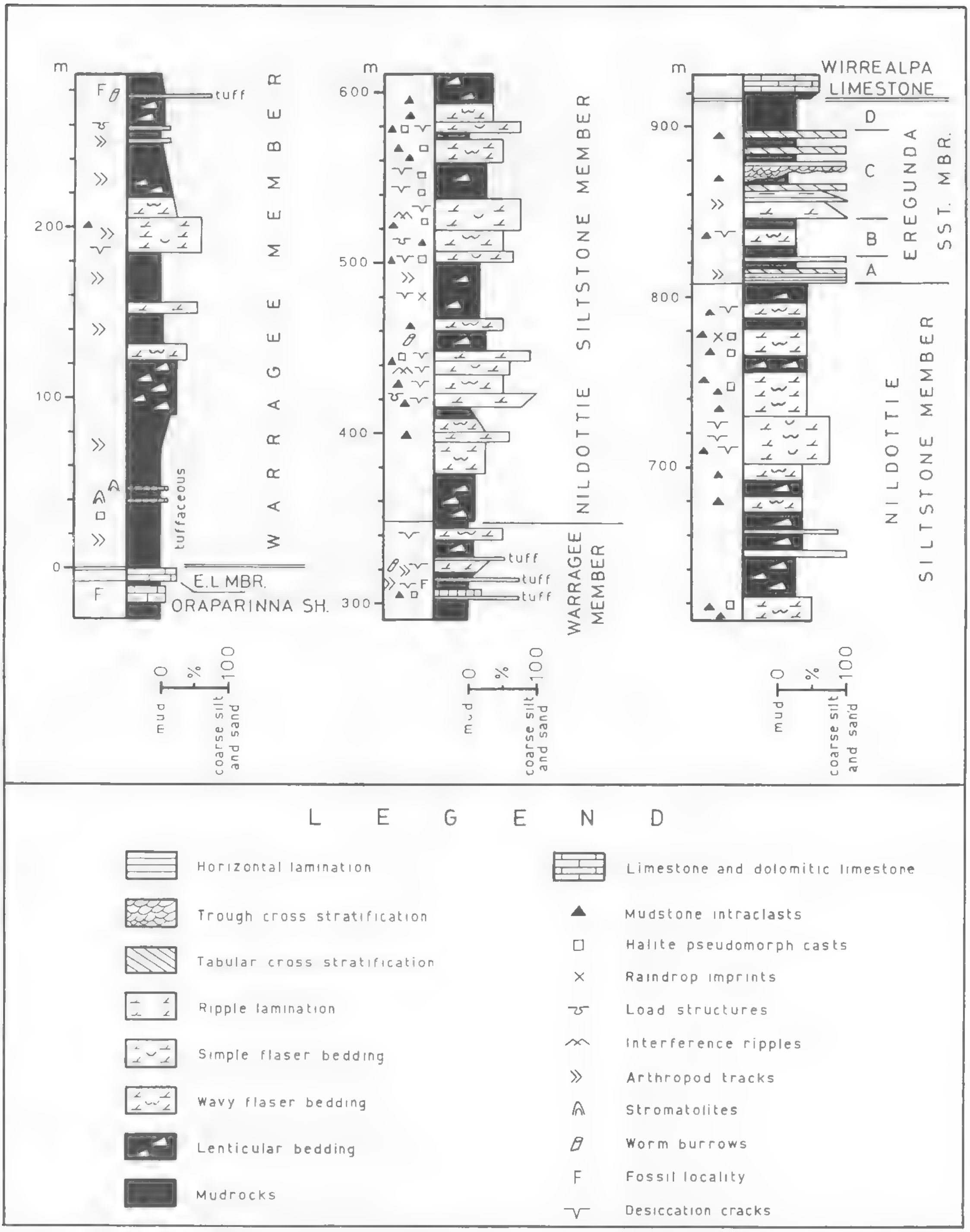


Fig. 3. Type section of the Billy Creek Formation, 2.5 km north of Ten Mile Creek in the Wirrealpa Basin. This section is also the type location for the Warragee Member, the Nildottie Siltstone Member, and the Eregunda Sandstone Member.

The Base of the Warragee Member

In most areas, the Warragee Member rests conformably on carbonates of the Hawker Group. Along the Heysen Range, in the central portion of the Wirrealpa Basin and at Mernmerna, a passage exists from the Edeowie Limestone Member of the Oraparinna Shale into the Warragee Member of the Billy Creek Formation (Moore 1979). In the northern portion of the Wirrealpa Basin near the Old Wirrealpa Mine, green shales of the Warragee Member overlie dolomitized Wilkawillina Limestone with apparent conformity. In the Mt Scott Range, red and green interlaminated silty shales of the Warragee Member rest directly on dolomitized stromatolites of the Ajax Limestone, also with apparent conformity. At Mount Frome, the Warragee Member rests sharply on an uneven surface of very sandy limestone, presently mapped as Wilkawillina Limestone (Dalgarno & Johnson 1966), and the contact is interpreted as a minor disconformity or hiatus. Further to the north near Chambers Gorge, light olive shales of the Warragee Member rest conformably on flaggy, micritic limestone of the Moorowie Formation (Moore 1979).

The Top of the Warragee Member

A transition occurs from the Warragee Member into the overlying Nildottie Siltstone Member. In the type section (Section BC–B, Figs 2 & 4), the contact is taken at the top of the last major green shale interval, which occurs approximately 32 m above the top of a prominent, 2 m thick, buff-coloured dolomite. The boundary between variegated and completely red sediment is chosen as the top of the Warragee Member, because this is the only feature which can be used consistently through-

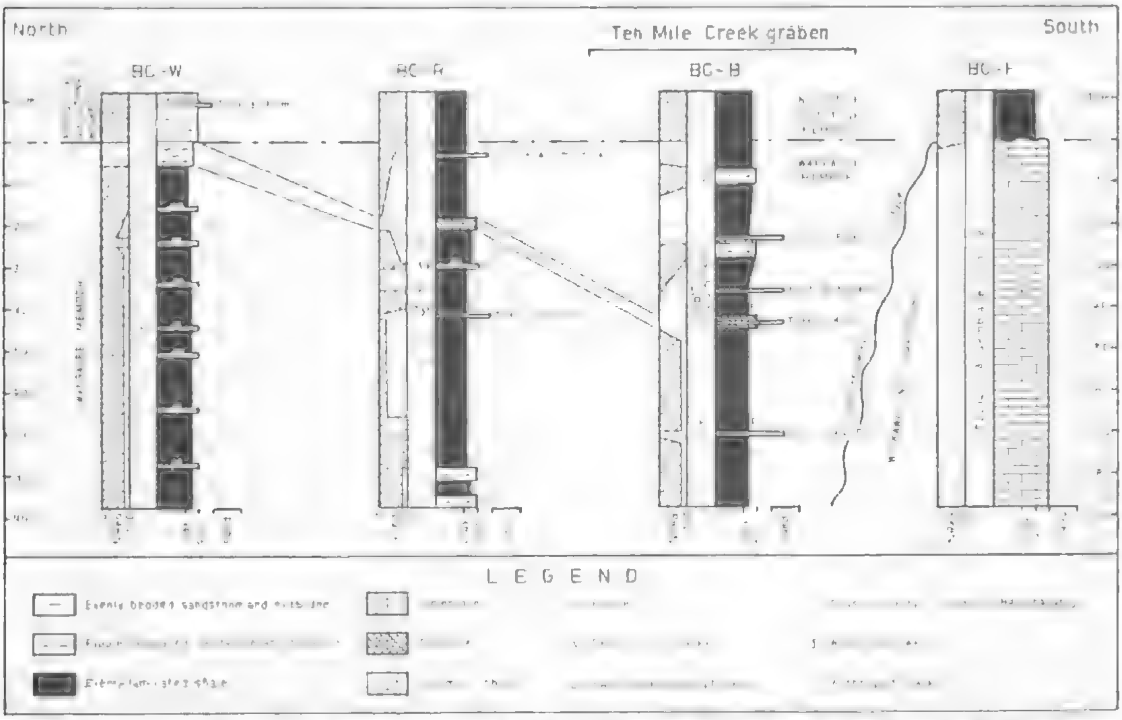
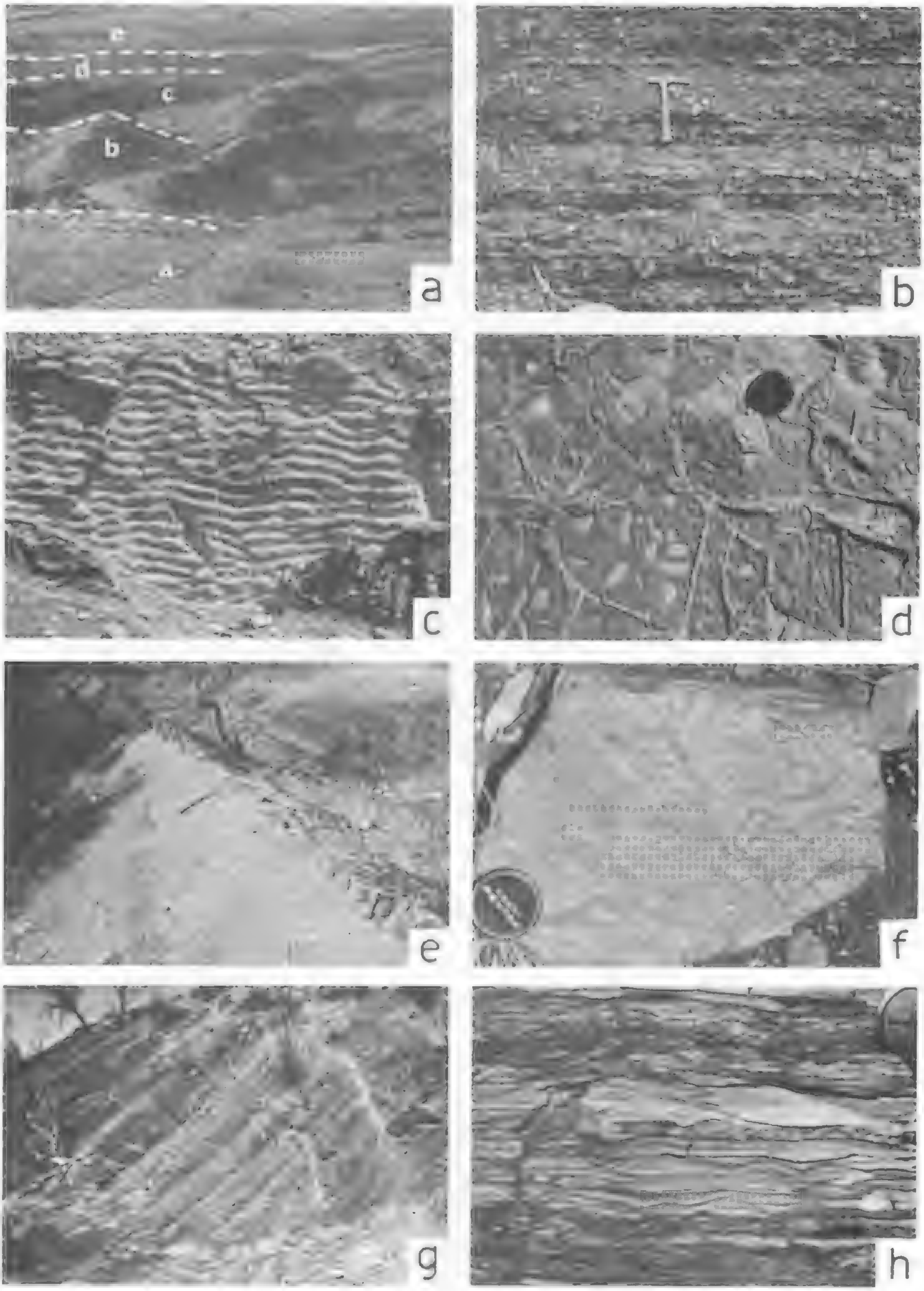


Fig 4. Location of major tuff beds, dolomite and fossiliferous intervals in upper portion of Warragee Member in Wirrealpa Basin (see Fig. 2 for locations of stratigraphic sections). All of the tuff beds shown have been mapped continuously throughout the area of outcrop. The thick dolomite marker bed occupies a similar stratigraphic position in relation to the tuffs in all of the outcrops, and thus is considered to be essentially isochronous over its area of outcrop. The Warragee Member—Nildottie Siltstone Member boundary however is markedly time transgressive in the Wirrealpa Basin, and is considered to be a very delicate palaeoenvironmental indicator. The transition from variegated to all-red sediment (i.e. the member boundary) is interpreted as representing a minor regressive event, and indicates that persistent shallow water, oxidising conditions typical of the Nildottie Siltstone Member developed first in the north and south and then slowly extended into the central, more basinal areas (the Ten Mile Creek graben: Section BC-B) as the regression continued.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out the area of outcrop. The prominent dolomite bed which outcrops in the upper portion of the Warragee Member in the type section is recognised only in the Wirrealpa Basin, and even then it is absent from the most northeasterly outcrops near Wirrealpa.

In general however, the Warragee Member is differentiated from the overlying Nildottie Siltstone Member in the following ways:

(a) The Warragee Member is dominated by shale and fine to medium siltstone, whereas the overlying member is coarser grained.

(b) The Warragee Member contains common green, greyish green and grey interbeds in the dominantly red clastic sequence. Non-red intervals in the overlying Nildottie Siltstone Member are rare and very thin.

(c) The Warragee Member contains minor limestone and dolomitic limestone interbeds, which are absent from the overlying member.

Internal Stratigraphy

(a) Shale—siltstone lithotype

The Warragee Member is dominated by evenly laminated shale and fine to medium siltstone (Fig. 5b). The majority of the sequence is greyish red in colour, although shades of green and grey are common. Grey to buff coloured shales are typically weakly calcareous, and gradations into dolomite or dolomitic limestone may occur. Coarse siltstone to very fine sandstone interbeds are uncommon and occur mainly as thin, evenly laminated interbeds in the shaly sequence. Thicker units, rarely up to 15 cm, are ripple laminated (Fig. 5c). Desiccation cracks are uncommon (Fig. 5d). Minor, small (1–6 mm) halite casts are recorded, especially in the Heysen Range sections. Tracks attributed to trilobites occur sporadically throughout the member. Horizontal and subvertical worm burrows occur mainly in the upper portion of the Wirrealpa Basin sequences, and may be found with the trilobite *Balcoracania flindersi* (Pocock 1970).

(b) Carbonate lithotype

Carbonate units typically occur in poorly defined cycles, which grade from red shale through green and grey shale into carbonate (Fig. 5e). The cycles are best developed in the Wirrealpa Basin and Mount Frome outcrops. Dolomite and dolomitic limestone beds are typically 2–10 cm thick and comprise flat-laminated to highly undulose dolomicrite to dolomicrosparite. Halite imprints and desiccation cracks are commonly associated with the flat-laminated units. Undulose laminations are attributed to sediment binding on algal mats. Small, low domal stromatolites are developed in a few cases, principally in the Wirrealpa Basin. In the upper portion of the Wirrealpa Basin sequence, a buff-coloured dolomite up to 2 m thick may form a prominent marker horizon. The dolomite is evenly laminated and contains abundant halite casts and desiccation cracks.

(c) Tuffaceous lithotype

The majority of the tuffaceous units in the Billy Creek Formation occur in the Warragee Member. Seven major tuffaceous horizons (at least 4 cm thick) are recognised in the type section and have been confirmed by petrographic analysis. At Mount Frome volcanic detritus is disseminated throughout the lower portions of the member. Tuffaceous intervals

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Fig. 5 (a) Type section of the Billy Creek Formation 2.5 km north of Ten Mile Creek in the Wirrealpa Basin. The three members of the Billy Creek Formation are the Warragee Member b, the Nildottie Siltstone Member c, and the Eregunda Sandstone Member d. The Billy Creek Formation rests conformably on the Oraparinna Shale a and is overlain by the Wirrealpa Limestone e. (b) Red and green interlaminated shales of the Warragee Member. Thin silt interbeds are evenly laminated to ripple laminated. Location: approximately 3 km north of the Brachina Gorge. (c) Symmetrically rippled greyish red coarse siltstone of the Warragee Member. Location: type section 2.5 km north of the Ten Mile Creek in the Wirrealpa Basin. (d) Desiccation cracks in red shale of the Warragee Member, infilled with green to greenish siltstone. Location: 4 km north of the Balcoracana Creek in the Wirrealpa Basin. (e) Cyclic sedimentation in the Warragee Member. Red silty shale grades upwards through greyish green shale into buff coloured stromatolitic dolomite. A short passage back into red silty shale is present. Location: type section, 2.5 km north of Ten Mile Creek. (f) Worm burrows in salmon pink tuffaceous siltstone of the Warragee Member. Location: type section, 2.5 km north of Ten Mile Creek. (g) General view of outcrop of the Nildottie Siltstone Member. Location: Section BC R, 2 km north of Balcoracana Creek. (h) Simple and wavy flaser bedding in red-beds of the Nildottie Siltstone Member. Note the presence of small mudflake intraclasts. Location: Balcoracana Creek.

are uncommon in the Heysen Range sections and only one has been identified by the author in the Mount Scott Range.

The tuffaceous units are recognised primarily on the basis of colour (Dalgarno 1964). Tuffaceous bands in red shale-siltstone are either salmon pink or bright olive green. The pink bands are generally coarse silt-size, and contain abundant shards of poorly twinned plagioclase with albitic rims. The green colour in many of the tuffaceous units is due to extensive alteration to chlorite. Rarely, devitrified shards are recognisable.

In the Wirrealpa Basin, two prominent tuffaceous units, 40–50 cm thick, occur in the upper portion of the member (tuffs 1 and 3, Fig. 4). Near Balcoracana Creek (Section BC–R), tuff No. 1 forms drapes over preexisting symmetrical ripples. In the type section (BC–B), tuff No. 3 is horizontally burrowed (Fig. 4f) and contains small resting marks attributed to trilobites. Reworking of some of the tuffaceous detritus has occurred and several of the thicker tuff bands contain a variety of nonvolcanic, sandy detritus. In some cases, tuffaceous units are ripple laminated with symmetrical ripples developed on the upper surface.

Palaeontology

Emuellid trilobites were first recorded in the Billy Creek Formation by Dalgarno (1964). The fossil locality is a small tributary south of Balcoracana Creek, and is shown on the *Blinman* 1:63 000 Geological sheet (Dalgarno *et al.* 1964). The trilobites were subsequently described by Pocock (1967[3], 1970) who named them *Balcoracania flindersi*. As now defined, the trilobites occur in the upper portion of the Warragee Member, "approximately 25 ft below the lowest of three tuffaceous bands" (Dalgarno 1964).

During the course of this study, additional collections of *Balcoracania flindersi* were made from south of Balcoracana Creek, "approximately 9 m below a prominent, 40 cm thick, pink tuff bed, identified as 'tuff I' in Fig. 4. The trilobites were also found in a similar stratigraphic horizon north of Balcoracana Creek (Section BC–R) and in the type section north of the Ten Mile Creek (Fig. 4). Mass mortality, associated with desiccation, is indicated in most cases. Despite an intensive search, trilobites have not been located in any other outcrops of the Warragee Member.

Regional Variation

The Warragee Member is partly characterised by its fine grain size and poorly developed grain size variation. This is true both within and between sections. Coarse siltstones and fine sandstones occur mainly in the middle, red unit of the member and are most common in the thick Ten Mile Creek graben and Heysen Range sections (BC–B, BU–A, BR–A, BR–C). These sections also contain the greater proportion of red coloured clastics and halite casts.

Carbonate units are particularly common in the Ten Mile Creek graben outcrops, and occur sporadically throughout the Wirrealpa Basin, Mount Frome and Chambers Gorge sections. They are uncommon in the eastern areas, such as along the Heysen Range and at Mt Scott.

Depositional environment of the Warragee Member

There is abundant evidence of marine influence throughout the Warragee Member and most of the terrigenous muds are believed to have been deposited on the margins of a very shallow epi-continental sea. Infrequent subaerial exposure is indicated by desiccation cracks. Furthermore since there is only minor evidence of evaporite formation, it is likely that halite and gypsum were only formed in shallow restricted pools and on supra-tidal flats. Thus, the presence of halite casts may be assumed to represent high intertidal to supratidal conditions for those parts of the sequence in which they occur.

Carbonate units are typically fine-grained and dolomitic. Their association in some cases with halite casts and desiccation features suggests that they were deposited on intertidal flats and in very restricted, shallow lagoons. Evaporite minerals have not been found in association with stromatolitic carbonate, which probably formed in the subtidal zone or on intertidal flats subject to frequent inundation.

Soil horizons, massive mudstones and pisolitic calcrete profiles have not been recognised and thus it is assumed that no significant amount of the Warragee Member as

[3] Pocock, K. J. (1967) An aberrant group of trilobites from the Lower Cambrian of South Australia: systematics, functional morphology, segmentation and growth. Ph.D. Thesis, Univ. of Adelaide (unpublished).

presently exposed was formed by alluvial flooding in the continental (alluvial plain) environment. The sequence thus accumulated by infilling of a shallow epicontinental sea and progradation of muddy tidal flats. Shale-carbonate cycles probably developed in response to minor imbalance between the rates of subsidence and sedimentation.

Stratigraphy of the Nildottie Siltstone Member

Introduction

Throughout the central Flinders Ranges and in the Mount Scott Range, the middle portion of the Billy Creek Formation is dominated by greyish red siltstone, with minor shale and fine sandstone (Fig. 5g). The sequence is herein termed the Nildottie Siltstone Member. The name is derived from Nildottie Spring, which is located approximately 17 km northwest of the Wirrealpa homestead, in the Wirrealpa Basin.

The Nildottie Siltstone Member attains its maximum measured thickness of 460 m in the Ten Mile Creek graben, but generally thins towards the north. The type section (Section BC–B, Figs. 2, 3 and 5a) is located in an area of undulatory topography, 2.5 km north of the Ten Mile Creek. It corresponds with the middle portion of Daily's (1956) type section of the Billy Creek Formation.

The Base of the Nildottie Siltstone Member

In most outcrops, the Nildottie Siltstone Member rests conformably on red and green shale of the Warragee Member, as discussed above. However, in the southern portion of the Wirrealpa Basin south of the Ten Mile Creek graben, the Nildottie Siltstone Member rests directly on Wilkawillina Limestone containing Daily's (1956) Faunal Assemblage No. 2. Although the area is complicated by faulting, it is possible that the Nildottie Siltstone Member originally rested disconformably on Wilkawillina Limestone.

The Top of the Nildottie Siltstone Member

In all outcrops, the Nildottie Siltstone Member is conformably overlain by red micaceous arkoses of the Eregunda Sandstone Member. The contact is generally sharp and well defined. Load structures and flute casts may occur at the base of the sandstone, especially where it overlies very shaly sequences.

Internal Stratigraphy

The Nildottie Siltstone Member is dominated by greyish red, ripple laminated coarse siltstone. Minor sandstone, fine siltstone and shale occur sporadically in the lower portion of the member in a few localities. With increased silt content, evenly laminated shales grade into wavy laminated, poorly defined flaser bedded, and finally ripple laminated siltstones devoid of clay laminae. (Fig. 5h). Sandstones are rare and typically occur as rippled or horizontally laminated units, 5–15 cm thick.

A feature of the Nildottie Siltstone Member is the abundance of rippled bedding surfaces. The majority of the ripples are very continuous, short wavelength (1–3 cm), low amplitude (4–10 mm), symmetrical and near-symmetrical forms (Fig. 6a). Highly asymmetrical, catenary and straight-crested ripples are minor (Fig. 6b). Mudflakes, desiccation cracks, halite casts (Fig. 6c) and small load structures are commonly associated with the silty intervals and are abundant in some units. Raindrop imprints are known from several localities (Fig. 6d). Trilobite tracks and worm burrows are rare. The majority of the sequence is weakly calcareous, mainly due to a small proportion of calcite cement. However, some beds contain abundant calcite as vesicles, patches and veins. A few show evidence of gypsum replacement.

Palaeontology

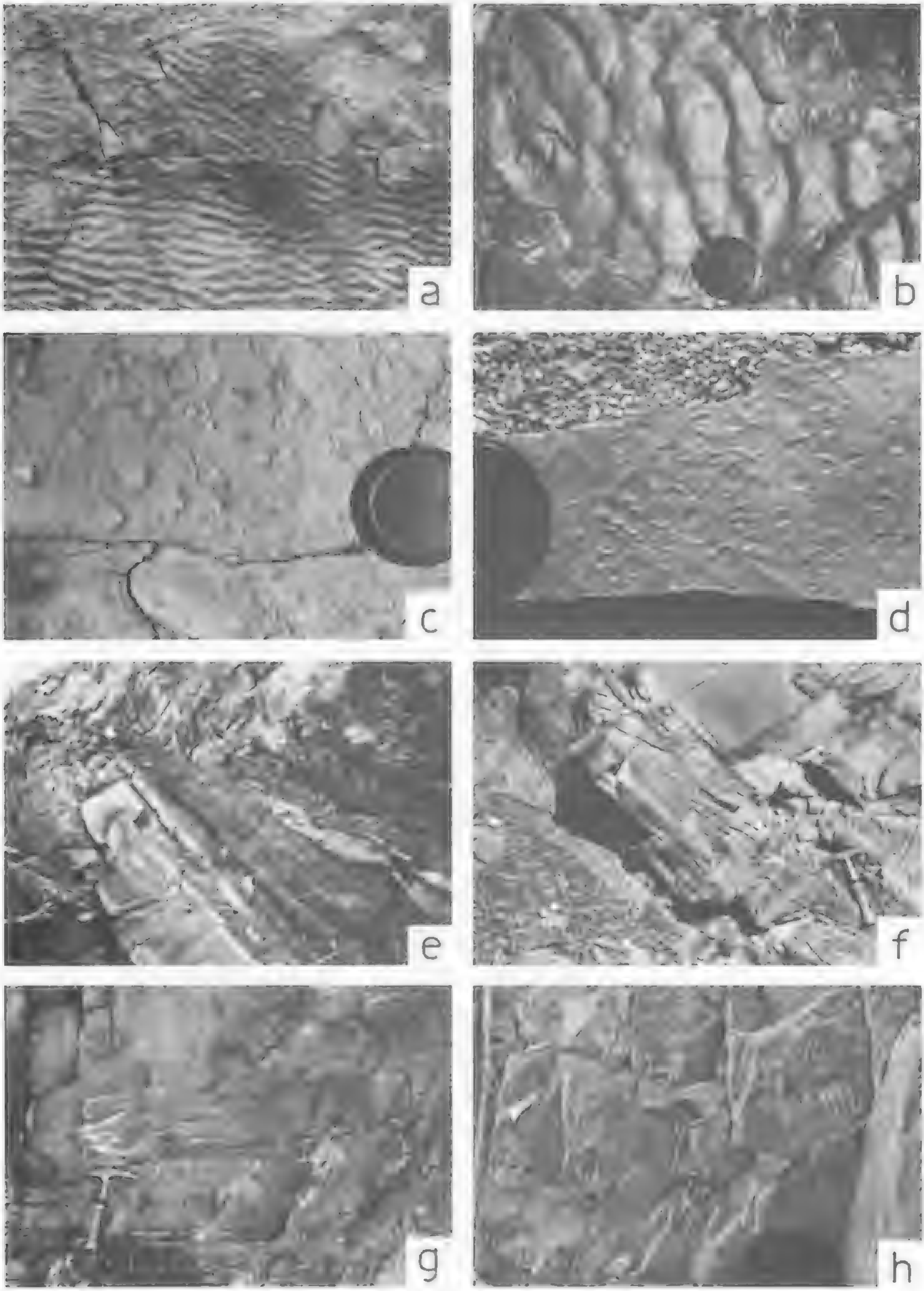
Worm burrows, and tracks attributed to trilobites are uncommon in the Nildottie Siltstone Member. No body fossils have been found to date.

Regional Variation

The Nildottie Siltstone Member is relatively consistent in character throughout its area of outcrop. In the Heysen and Mount Scott Ranges, the member is divisible into a lower shaly unit and an upper silty one. In general however, this coarsening-upward tendency is poorly expressed. In the eastern outcrops near Mount Frome and the Chambers Gorge, small tidal channels are rarely recorded in the sequence.

Depositional environment of the Nildottie Siltstone Member

The bulk of the Nildottie Siltstone Member comprises red shale and shaly siltstone which were deposited in a paralic environment. A general lack of cyclicity in the sequence suggests that there was a delicate balance between subsidence and sedimentation. The considerable lateral extent and thickness of the paralic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facies suggests that the palaeoslope was very low, and epeiric sea conditions pertained. A lack of coarse detritus in the sequence is further evidence of an extremely low amplitude, senile topography with sediment supply by sluggish, low competence streams. Thus, an extensive, muddy alluvial flood plain probably flanked a broad zone of intertidal sediments.

Intertidal and shallow subtidal, tide-influenced deposits constitute the bulk of the sequence. Evidence for tidal activity occurs in the intimate association of wave, current, flat-topped and interference ripples, along with desiccation cracks, mudflake breccias, halite casts, rare marine trace fossils and rain-drop imprints. In addition, poorly defined wavy and lenticular bedding occur in the Nildottie Siltstone Member, and are identical in character to bedding structures in Recent, fine grained tidal deposits from the Gulf of California (Thompson 1968).

The tidal range during deposition of the Nildottie Siltstone Member is unknown, since there are no palaeotidal range sequences (cf. Klein 1971). However, the relative abundance of wave-formed ripples (commonly associated with desiccation cracks), suggests that tidal currents were relatively weak. The consistent bipolar orientation of the ripple marks also favours a low energy tidal origin for these sediments, with crests aligned subparallel to the coastline and currents directed on and off shore. The poor sorting of the sediment and a paucity of tidal channels are further evidence of weak tidal flux.

Stratigraphy of the Eregunda Sandstone Member

Introduction

Throughout the central Flinders Ranges and in the Mount Scott Range, the upper portion of the Billy Creek Formation is dominated by sandstone (Fig. 6e). This sandy sequence is herein termed the Eregunda Sandstone Member, after Eregunda Creek which dissects the sequence 7 km west-northwest of the Wirrealpa homestead.

The Eregunda Sandstone Member attains its maximum measured thickness of 166 m in Section BU–B, south of the Bunyeroo Gorge, and generally thins towards the north and northeast. The member is absent from Reaphook Hill and Mernmerna, where the upper portions of the Billy Creek Formation are missing, due to post-Cambrian erosion. The type section (Section BC–B, Figs. 2, 3 and 5a) is located 2.5 km north of the Ten Mile Creek. It corresponds to the upper 107 m of Daily's (1956) type section of the Billy Creek Formation.

The Top of the Eregunda Sandstone Member

A transition occurs from the Eregunda Sandstone Member into the overlying Aroona Creek and Wirrealpa Limestones. The transition zone (0.2–3 m thick), separates fine red siltstone and shale of the uppermost Eregunda Sandstone Member from prominently outcropping, well bedded limestone. It is characterised by thinly interbedded, greyish siltstone and microsparite, which may be dolomitic or possess wavy algal lamination (Youngs 1977).

Internal Stratigraphy

Sandstones dominate the sequence and are typically fine-grained, red, micaceous arkoses with common heavy mineral bands. They are poorly bedded to horizontally laminated, with minor tubular and rare trough cross-stratification (Fig. 6f). Channels, with associated mudstone-lag-conglomerate, are common in the Wirrealpa Basin outcrops (Fig. 6g), but comparatively rare elsewhere. Ripple-laminated

Fig. 6. (a) Symmetrical wave ripples in red siltstones of the Nildottie Siltstone Member. Location: 8 km south of Chambers Gorge. (b) Asymmetrical current ripples in red siltstone of the Nildottie Siltstone Member. Note the infilled desiccation crack in the bottom right of the photograph. Location: type section, 2.5 km north of Ten Mile Creek. (c) Imprints of hopper shaped halite crystals in red siltstone of the Nildottie Siltstone Member. Location: south-eastern end of the Mt Scott Range. (d) Raindrop imprints in red siltstone of the Nildottie Siltstone Member. Location: east of Mt Frome. (e) General view of the Eregunda Sandstone Member. Note the prominent scour surface, where red sandstones have eroded into the underlying shales. Location: Ten Mile Creek, Wirrealpa Basin. (f) Planar—tabular cross-stratification of the Eregunda Sandstone Member, overlying horizontally laminated, current lineated sandstone. The cross-stratification is erosionally overlain by poorly bedded red sandstone. Location: 12 km north of Brachina Gorge. (g) Prominent channel cut into horizontally laminated, current lineated, red sandstone of the Eregunda Sandstone Member. The channel is infilled with massive to poorly bedded, fine red sandstone. Location: Balcoracana Creek. (h) Arthropod tracks in fine micaceous siltstones of the Eregunda Sandstone Member. Location: Ten Mile Creek, in the Wirrealpa Basin.

sandstones are minor, and are best developed in the northern outcrops. along the Mt Scott Range and at Mt Frome. Trace fossils are mainly restricted to shaly units, however molluscan trails, worm burrows and trilobite tracks are common in evenly bedded to ripple-laminated sandstones in the Mt Scott Range.

The finer grained sediments of the Eregunda Sandstone Member comprise greyish red and rare green, micaceous, feldspathic siltstone and shale which are very similar to lithologies in the underlying Nildottie Siltstone Member. Mudstone intraclasts, desiccation cracks, symmetrical ripples and asymmetrical current ripples are all common in these lithologies. Halite pseudomorph casts occur at most localities and tracks attributed to trilobites are abundant throughout the region (Fig. 6h). The Eregunda Sandstone Member is generally divisible into four units (Fig. 2). Units A and C are dominated by sandstone, whereas units B and D comprise shale and siltstone with minor rippled sandstone interbeds.

Palaeontology

Tracks attributed to trilobites are common in the Eregunda Sandstone Member, and occur mainly in the fine-grained lithologies (Fig. 6h). Worm burrows and molluscan trails are common in the Mt Scott Range outcrops; however no body fossils have been found in the member to date.

Regional Variation

The sedimentological characteristics of the sandstone lithologies vary considerably across the region, whereas the finer-grained sediments are relatively uniform in character. A feature of the sandy sequences is their lateral variability, and siltstone and shale interbeds cannot be used to correlate adjacent stratigraphic sections.

In the Wirrealpa Basin, current lineated sandstones are prominent, and are commonly associated with massive sandstones and erosional surfaces. In the thicker sections along the Heysen Range, current lineated sandstones are less abundant, and large scale cross-stratified and ripple laminated sandstones occupy an increased proportion of the sequence. Near Mt Frome and along the Mt Scott Range, ripple laminations are common in the sandstone units, which also contain trilobite tracks and several prominent bioturbated intervals. A general conclusion is that the thicker sequences of the Eregunda Sandstone Member contain a greater proportion of high energy, current laid deposits.

Depositional environment of the Eregunda Sandstone Member

Little attempt has been made to interpret the environment of deposition of the Eregunda Sandstone Member, although Pierce[4] suggested that the sequence in the Wirrealpa Basin possessed deltaic characteristics. In the course of this study it became apparent that there were two clearly distinguishable lithological associations in the member.

The fine grained, shale-siltstone association commonly contains marine trace fossils, desiccation cracks and halite casts, and is characterised by poorly developed tidal stratification. A low energy intertidal to shallow subtidal origin is envisaged. The coarse-grained association is dominated by current laid sandstones, commonly arranged in waning current cycles. Ideal cycles display the sequence—scoured surface, poorly bedded sandstone, horizontally laminated sandstone, and tabular cross-stratified sandstone with linguoid ripples of the upper surface. Marine trace fossils are very uncommon in these units, although their abundance increases towards the north and northeast, where the sand units are thin and relatively distal with respect to the terrigenous source area.

The two facies associations are intimately interbedded. This vertical and lateral juxtaposition of tidal mudflat deposits and current-laid sandstones indicates that the Eregunda Sandstone Member was deposited in a shoreline environment, probably as a complex of fluvial-dominated deltas which built out into a shallow epicontinental sea.

Regional correlations

Correlation between the Billy Creek Formation and other units in the Adelaide 'Geosyncline' and on the Stuart Shelf are summarised by Daily (1976, Fig. 8). The Yarrawurta Shale, which was deposited on the Stuart Shelf to the west of the Adelaide 'Geosyncline' is similar in character to the Warragee Member of the Billy Creek Formation, comprising approximately 120 m of "micaceous, calcareous. red-brown, pink, purple or green-

[4] Pierce, P. R. (1969) Cambrian geology south of the Wirrealpa diapir, Flinders Ranges, South Australia. B.Sc. Hons Thesis, Univ. of Adelaide (unpublished).

grey shales and siltstones" (Johns 1968). According to Daily (1976) "the widespread occurrence of 'bird's-eye' limestone, dolomite and stromatolites near the top of the Andamooka Limestone, Ajax Limestone, and in the youngest phases of the Wilkawillina Limestone and the Moorowie Formation point to a general regression of the sea before the influx of redbed clastics which gave rise to the Yarrawurta Shale and the Billy Creek Formation". Thus, the northern portion of the Adelaide 'Geosyncline' was relatively stable at this period of time, and a slow regression is indicated by much of the Billy Creek Formation stratigraphy.

In the southern portion of the Adelaide 'Geosyncline' however tectonic movements were pronounced. At the close of the period marking Hawker Group sedimentation, the Kanmantoo Trough was formed (Daily & Milnes 1971, 1972, 1973; Thomson 1969). Compensating uplifts occurred to the north and west, resulting in considerable erosion of the uplifted areas and deposition to the south of a thick sequence of shallow-water, shelf sediments which are in part conglomeratic. The earth movements, termed the Kangarooian Movements by Daily (1969) and Daily & Forbes (1969), appear to have affected the whole of the Adelaide 'Geosyncline' and may be responsible for local disconformities at the base of the Billy Creek Formation in the Flinders Ranges as well as accounting for the regressive nature of the red-bed sequence. Correlation of the Kangaroo Island northeast coast sediments with the Billy Creek Formation is made on the basis of the trilobite family Emuellidae, and in particular the trilobite genus *Balcoracania* Pocock. In the Flinders Ranges, *B. flindersi* occurs in the upper portion of the Warragee Member, and on Kangaroo Island *B. dailyi* occurs in a thin burrow-mottled limestone and associated shales near the top of the White Point Conglomerate[5]. The Kangaroo Island northeast coast sequence is in turn correlated with the metasediments of the Kanmantoo Group, mainly on the basis of lithological similarities between the two sequences.

Biostratigraphic correlation is possible between the Billy Creek Formation and the upper portion of the Cymbric Vale Formation in northwestern New South Wales, although the correlation is somewhat indirect. The lower 1500 m of the Cymbric Vale Formation are correlated with the Ajax Limestone (Kruse 1977), however a younger fauna, containing an abundance of *Estaingia bilobata* has been reported by Warris[6] and Öpik (1968, 1976) from the uppermost portion of the Cymbric Vale Formation. *Estaingia bilobata* is a prominent species in the lower portion of the Emu Bay Shale and also occurs in the upper portion of the White Point Conglomerate on Kangaroo Island, and thus occupies a similar stratigraphic position to the *Balcoracania* discussed above. Thus a correlation is suggested between the upper portion of the Cymbric Vale Formation in northwestern New South Wales, the upper portion of the White Point Conglomerate or the lower portion of the Emu Bay Shale on Kangaroo Island, and the upper portion of the Warragee Member in the Flinders Ranges.

More tentative correlations of the Billy Creek Formation have been suggested by Freeman (1966) and Wopfner (1966). Freeman (1966) related the Billy Creek Formation to a period of non-deposition in the Bancannia Trough, suggesting more extreme uplift in the latter area. Wopfner (1966) described Cambro-Ordovician sediments from the northeastern margin of the Lake Frome Embayment at Mount Arrowsmith, New South Wales, and tried to relate the sequence to the outcrops in the Flinders Ranges. On lithological grounds, he correlated his members A and B at Mt Arrowsmith with the Billy Creek Formation. However, Wopfner's member A contains the Middle Cambrian trilobite *Xystridura*, making this correlation and the correlations suggested by Youngs (1977) between the Wirrealpa Limestone and the Mt Arrowsmith sequence, untenable (Daily pers. comm., 1977).

Conclusions

The three members of the Billy Creek Formation defined above constitute a coarsening-upward sequence from shale, through siltstone, to sandstone. Evidence of very shallow water deposition and subaerial exposure is abundant throughout the sequence, and thus the upward change in lithology cannot be directly attributed

[5] Daily, B. (1977) Notes on the geology of Kangaroo Island. Geol. Soc. Aust. (S. Aust. division) field conference, October 1977 (unpublished).

[6] Warris, B. J. S. (1967) The stratigraphy and palaeontology of northwestern New South Wales. Ph.D. Thesis, Univ. of Sydney (unpublished).

to relative marine transgression or regression. Rather, it is a response to progressive tectonic uplift (the Kangarooian Movements) mainly to the south and southeast of the study area.

Initial tectonic activity associated with the Kangarooian Movements terminated the major phase of Lower Cambrian carbonate deposition (the Hawker Group) and promoted the development of muddy tidal flats (the Warragee Member) on the margins of a much-restricted basin. Red-beds formed in response to evaporitic and emergent conditions. Subsequent uplifts increased the palaeoslope, increased stream competence, and released silt and fine sand into the basin of deposition forming the sequence herein termed the Nildottie Siltstone Member. The final uplifts further increased topographic relief in the source area and a complex of fluvial-dominated deltaic sands (the Eregunda Sandstone Member) prograded across the basin of deposition. Palaeocurrent data for the Eregunda Sandstone Member suggests that the source of the sand for this unit was the Broken Hill-Olary basement high. The overlying Wirrealpa Limestone accumulated during a period of relative quiescence prior to the main phase of red-bed clastic deposition (the Lake Frome Group) which probably terminated sedimentation in the Adelaide 'Geosyncline'.

Acknowledgments

The author wishes to acknowledge discussion and helpful criticism by Dr B. Daily and Mr D. Gravestock (University of Adelaide) and Mr R. Dalgarno (South Australian Department of Mines and Energy).

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A NEW STHENURINE KANGAROO (MARSUPIALIA, MACROPODIDAE) FROM SOUTHEASTERN SOUTH AUSTRALIA

BY ROD WELLS & PETER MURRAY

Summary

A new microdont species of Sthenurus, similar in size to S. occidentalis, with molar teeth resembling those of S. gilli is described from Pleistocene cave deposits in southeastern South Australia.

A NEW STHENURINE KANGAROO (MARSUPIALIA, MACROPODIDAE) FROM SOUTHEASTERN SOUTH AUSTRALIA

by ROD WELLS[1] & PETER MURRAY[2]

Summary

WELLS, R. & MURRAY, P. (1979) A new Sthenurine kangaroo (Marsupialia, Macropodidae) from southeastern South Australia. *Trans. R. Soc. S. Aust.* **103**(8), 213-219, 30 November, 1979.

A new microdont species of *Sthenurus* similar in size to *S. occidentalis*, with molar teeth resembling those of *S. gilli* is described from Pleistocene cave deposits in southeastern South Australia.

Introduction

Excavation of the extensive vertebrate fossil deposits at Victoria Fossil Cave, Naracoorte, South Australia (Wells 1975) is yielding large numbers of extinct Sthenurine kangaroos including *Procoptodon rapha* (Owen), *Sthenurus brownei* Merrilees, *S. occidentalis* Glauert, *S. gilli* Merrilees, *S. atlas* Owen, *S.* cf. *andersoni* Marcus and a new form not compatible with those reviewed by Bartholomai (1963) and Tedford (1966) or described by Marcus (1962) and Merrilees (1965, 1967).

The new species is named *Sthenurus maddocki* in memory of the late Ernest Maddock, past Director of National Pleasure Resorts and President of the Cave Exploration Group of South Australia, in recognition of his efforts in initiating the concept of the Victoria Fossil Cave tourist complex.

Methods

Mensuration follows Tedford (1966). All dimensions are in mm $\bar{x} \pm$ S.D. L = length; AW = anterior width protoloph (id); PW = posterior width metaloph, hypolophid. The dental nomenclature of Archer (1978) has been noted; that of Tedford (1966) has been retained.

Lower jaws have been associated with the skull by a process of elimination based on tooth dimensions, general morphology and occurrence in the same stratigraphic horizon. All referred specimens are deposited in the South Australian Museum (SAM).

Diagnosis

Skull: Similar to *Sthenurus occidentalis* Glauert (1910) and *S. brownei* Merrilees (1967), but differing in the greater lateral expansion of the frontals.

Mandible: Similar to but larger than that of *S. gilli* Merrilees (1965): mandibular symphysis long with a pronounced median dorsal groove and lacking the postero-ventral shelf of *S. gilli* and *S. occidentalis.*

Dentition: Smaller than *S. occidentalis* or *S. brownei;* similar to, but larger than, *S. gilli;* $I_{\overline{1}}$ narrow, lanceolate and procumbent; $P_{\overline{3}}$ narrower in length relative to *S. gilli* with labial crest separated anteriorly from lingual crest by a deep cleft; lophs of $M_{\overline{3}}$ directed antero-lingually, rather than at right-angles to saggital plane as in *S. gilli, S. occidentalis* and *S. brownei.*

Sthenurus (Simosthenurus) maddocki sp. nov.

Holotype: SAM P16999. Skull, partially compressed and containing complete, little-worn cheek dentition including $P^{\underline{3}}$, $Dp^{\underline{3}}$, $M^{\underline{1-4}}$.

Paratypes: SAM P16627. Left and right ramus of an adult mandible, fused at the symphysis including $I_{\overline{1}}$, $P_{\overline{3}}$, $M_{\overline{1-4}}$, but lacking right coronoid process and condyle and portion of left condyle. SAM P16513. Complete right ramus of juvenile including $I_{\overline{1}}$, $P_{\overline{2}}$, $DP_{\overline{3}}$,

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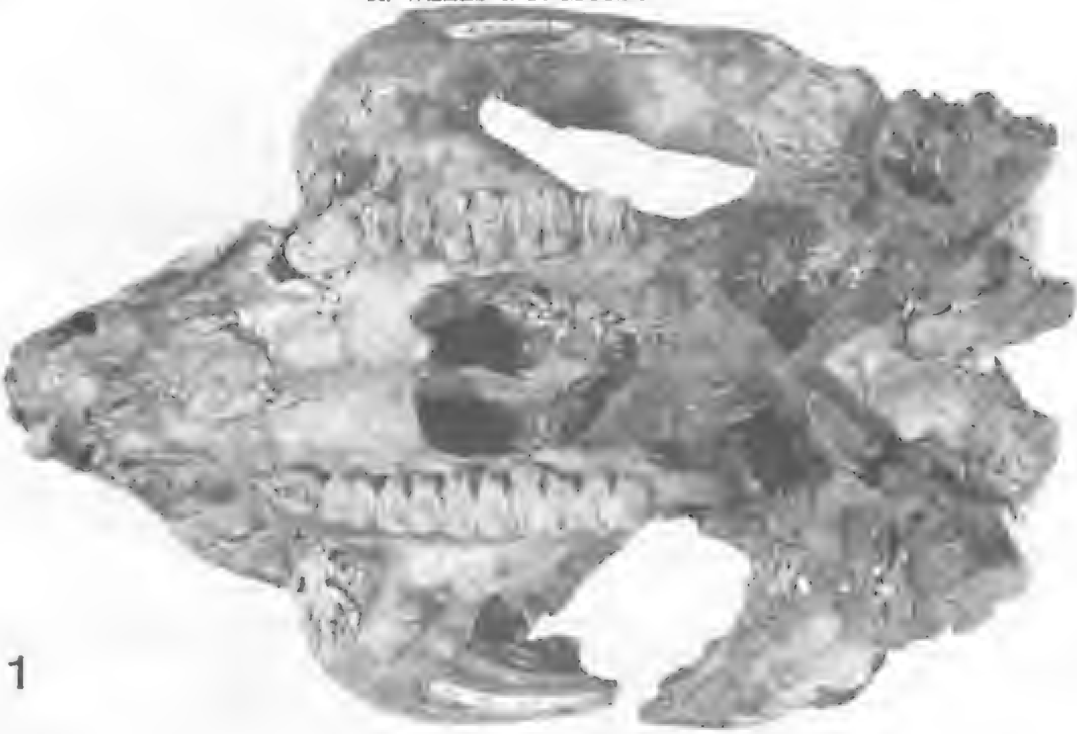
[2] Tasmanian Museum & Art Gallery, Hobart, Tas. 7000.



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2

Figs 1-2. *Sthenurus maddocki*; Holotype. SAM P16999. 1. Palatal aspect (slightly distorted due to crushing); 2. Dorsal aspect. Note inflated frontal.

$M_{\overline{1.2.3}}$ and $M_{\overline{4}}$ alveolus. SAM P16673. Adult mandible including $I_{\overline{1}}$, $P_{\overline{3}}$, $M_{\overline{1-4}}$, missing left and right coronoid processes and anterior portion of $P_{\overline{3}}$. SAM P16548. Fragmentary left mandible including $I_{\overline{1}}$, $P_{\overline{3}}$, $M_{\overline{1.2.3}}$ missing ascending ramus and ventral portion of mandible.

Type locality: Victoria Fossil Cave, Naracoorte, South Australia.

Age: Late Pleistocene.

Description and Comparison

Skull: (Figs. 1, 2) brachycephalic with exceedingly inflated frontal sinus produced by lateral expansion of anterior portion of frontal bones. This expansion cannot be attributed to the slight compression and distortion of this specimen. Facial region and diastema short as in *S. occidentalis*. Premaxillary extends anteroventrally as prominent horizontal shelf bearing V-shaped array of incisor alveoli. Narial opening, bounded laterally by narrow vertical wing of premaxillary, is broader than in *S. occidentalis* and similar to *S. brownei*. Only collapsed right nasal is present on holotype; broad and oblate posteriorly, tapering to a fine point anteriorly, which in an undamaged specimen would extend well forward of lateral border of nares. Facial surface of maxillary narrow but not as deep vertically as in *S. occidentalis* and *S. brownei*. Masseteric processes formed mainly by maxillary, short, blade-like, lack prominent lateral expansion evident in *S. occidentalis* and *S. brownei*.

Orbit more enclosed by overhanging postorbital process of frontal than in *S. occidentalis*, *S. brownei* or *S. gilli*. Jugal forms broad base and posterior margin to orbital rim. Deep zygomatic process of squamosal similar to that of *S. occidentalis* and *S. brownei*.

Large palatine vacuities extend anteriorly to a point opposite median valley of $M^{\underline{1}}$. Sufficient of left palatine bar remains to indicate weak structure similar to that of *S. occidentalis* and *S. gilli*.

Small, paired, incisive foramina open on to palate opposite posterior border of $I^{\underline{3}}$ alveoli. Palate has shallow median groove extending from incisive foramina, posteriorly to point opposite anterior root of $P^{\underline{3}}$. This groove flanked on each side by broad depressions extending from incisive foramina to anterior border of palatine vacuities. Diastema short, $I^{\underline{3}}$ alveolus — $P^{\underline{3}}$ 30.0 mm, representing 26% of palatal length (*S. occidentalis* 25%, *Procoptodon goliah* 25%; data derived from Tedford 1967). Cranium shows some elevation above plane of palate, not as pronounced as in *S. occidentalis*, although similar to *S. gilli*. Top of cranium narrow relative to frontal portion of skull, has two temporal lines which arise anteriorly from parietals near frontal-parietal suture and extend posteriorly to converge as saggital crest. Although somewhat distorted by crushing, occipital region broad with relatively short paroccipital processes.

TABLE 1
Measurements of skull of Sthenurus maddocki

	mm
Condylobasal length, ant. edge $I^{\underline{1}}$ alveolus to left post. edge occip. cond.	190
Max. width across frontal	100.7
Bizygomatic width	127.7
Width across paroccipital processes	82.7
Palatal length post. edge pal. bar to ant. edge $I^{\underline{1}}$ alveolus	115
Palatal width at ant. root $M^{\underline{1}}$	35.4
Palatal width at ant. root $M^{\underline{4}}$	35.8
Diastema length $I^{\underline{3}}$ $P^{\underline{3}}$	30

Upper Incisors: Upper incisors missing from holotype. However size of alveoli for these teeth indicate that $I^{\underline{1}}$ and $I^{\underline{3}}$ are similar in size while $I^{\underline{2}}$ is very small.

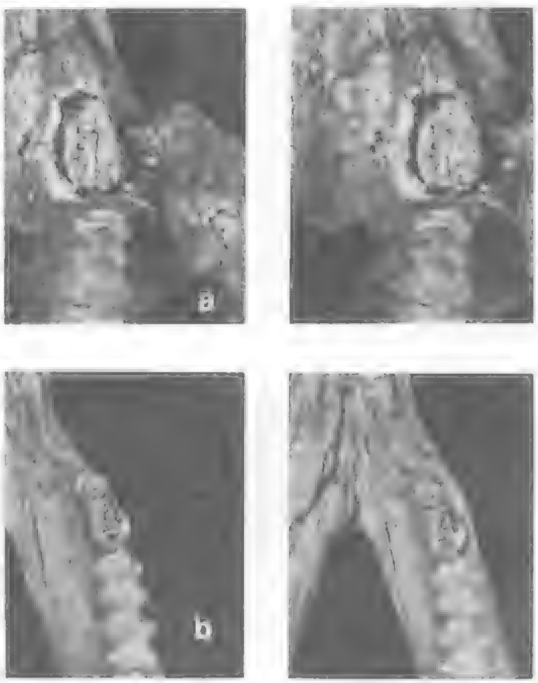

Fig. 3. A. Stereo pair of $P^{\underline{3}}$, Holotype, SAM P16999. B. Stereo pair of $P_{\overline{3}}$, Paratype, SAM P16627.

Figs 4-5. *Sthenurus maddocki* mandibles. 4. Dorsal aspect; 5. Lateral aspect.

p^{2}: A subrectangular tooth (L 9.4, AW 7.1, PW 8.1) narrower but similar in length to Dp^{2}. Possesses high labial crest and low lingual crest. The shallow longitudinal basin enclosed by these crests crossed by fine ridglets and, posteriorly, by single transverse ridge. Labial crest divided into three cuspules by series of vertical grooves that extend down labial face of crown.

p^{3}: Left p^{3} (Fig. 3a) has been exposed in its crypt by removing p^{2}, Dp^{2}. It is a large subrectangular tooth (L 16.2, AW 8.3, PW 10.1) bearing an enclosed longitudinal basin, flanked by parallel labial and lingual crests which in unworn specimen converge anteriorly and posteriorly. Longitudinal basin is crossed by transverse laminae and filled with plicae. Labial crest behind anterior cusp divided into series of cuspules by vertical grooves on labial face of crown. Posterolabial side of tooth features prominent cusp similar to that found in *S. occidentalis*.

Dp^{3}: Completely molariform, similar in proportion though smaller than M^{1}. (L 9.7, AW 8.5, PW 8.6).

Upper molars: Molar tooth rows gently recurved, converging anteriorly and posteriorly, with greatest width of palate occurring across protolophs of M^{2} and M^{3}. A similar curvature of the molar tooth row occurs in the undistorted lower jaw.

Upper molars increase in size from M^{1} to M^{3}.

TABLE 2

Measurements of upper molars of S. maddocki, *P16999*

	M^{1}	M^{2}	M^{3}	M^{4}
L	11.0	11.3	11.7	10.6
AW	10.2	12.1	12.2	10.8
PW	10.1	10.7	10.7	9.2

Molars are broader across protoloph than metaloph: this condition most marked in M^{4}. Low-crowned, trenchant lophs convex anteriorly and separated by a broad median valley. Anterior faces of lophs finely crenellate, while the posterior faces are more coarsely ornamented.

Well developed anterior cingulum extends labially and ventrally to apex of paracone. An incipient mid-link is formed from a weak crest descending posteromedially from protocone. Median valley falls away in a deep groove to base of crown on lingual side of mid-link. A narrow post-link arises from apex of hypocone, descending labially to base of metacone.

Lower Jaw: Mandibles (Figs. 4, 5) short and stout, similar to *S. occidentalis*, but with pronounced distal upward curving of tooth row. Long and gentle sloping symphysis, extending to point opposite posterior root of P_{3}, lacks postero-ventral shelf characteristic of *S. gilli* and *S. occidentalis* (Fig. 6). Two elongate pits for insertion of genial musculature occur on lingual and posterior portion of symphysis, and a median dorsal groove extends anteriorly to incisor alveoli. Anterior mental foramen opens ahead of P_{3} and below groove for buccinator musculature. Buccinator groove a prominent feature in Simosthenurines (Murray & Wells in prep.), arises at incisor alveolar border, sweeps posteriorly in a shallow arc above mental foramen and descends to point below anterior root of M_{2}. Posterior mental foramen opens in mid-labial aspect of mandible below anterior root of M_{3}. Digastric sulcus begins below the anterior root of M_{3}, is deep dorso-ventrally and similar in form to that of *S. occidentalis*, and not as pronounced as in *S. brownei*. Anterior root of ascending ramus lies opposite anterior part of M_{4}, as in *S. gilli*

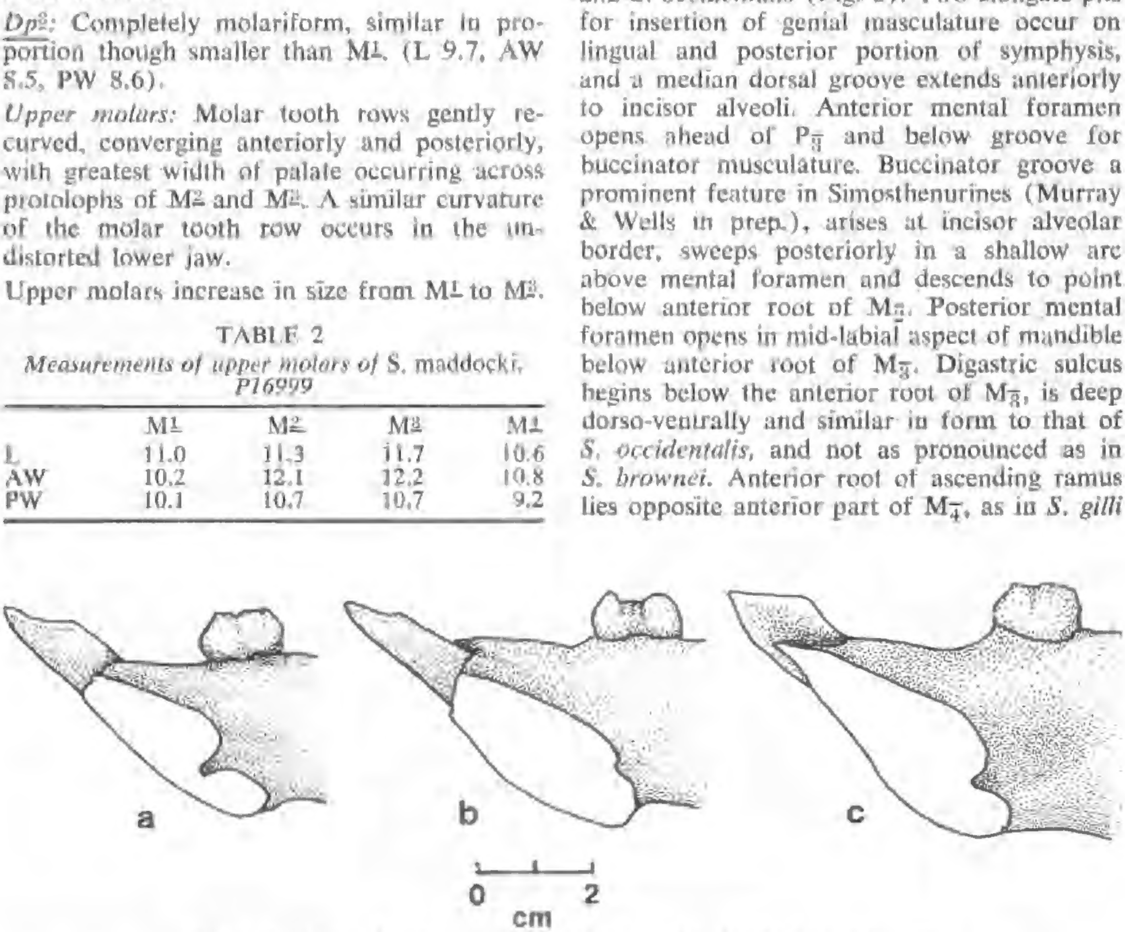

Fig. 6. Symphyseal union; A. *S. gilli*; B. *S. maddocki*; C. *S. occidentalis*.

and *S. occidentalis*. Angular process preserved only in juvenile mandible (P16513). It rises at right angles to mandible and is perfectly straight in both lateral and anterior aspects; a condition similar to *S. occidentalis*.

Lower incisors: Narrow (width at alveolar margin $\bar{x}$ 6.43±0.63, n 4) lanceolate and more procumbent than in *S. gilli*, *S. brownei* or *S. occidentalis*. They have a tapered crown and nearly horizontal occlusal plane.

$P_{\bar{2}}$: Smallest tooth in lower dentition (L 7.8, AW 4.8, PW 5.8). A prominent anterior cusp gives rise to lingual crest with two small cuspules. A weak labial crest encloses small longitudinal basin. There is an incipient development of a postero-labial cusp.

$P_{\bar{3}}$: (Fig. 3b) is a highly distinctive feature of *S. maddocki*. It is narrower relative to length than in either *S. gilli*, *S. brownei* or *S. occidentalis* ($\bar{x}$ L 15.9±0.3, AW 6.3±0.72, PW 8.2±0.69, n 3) and labial crest is separated anteriorly from lingual crest by deep cleft. Descending from prominent anterior cusp, lingual crest is divided into four cuspules by vertical grooves in lingual face of crown, and from these ascends postero-lingual cusp. Arising from base of postero-lingual cusp, short labial crest arcs dorsally and labially to the postero-labial cusp, terminating abruptly to leave an anteriorly open median valley. The median valley is traversed by series of small ridglets.

TABLE 3

Measurements of lower molars of S. maddocki

	$M_{\bar{1}}$	$M_{\bar{2}}$	$M_{\bar{3}}$	$M_{\bar{4}}$
n	4	4	4	2
L	10.3 ±0.29	11.13 ±0.48	12.03 ±0.05	11.75 ±0.07
AW	8.23 ±0.21	9.28 ±0.21	10.15 ±0.30	10.20 ±0.28
PW	8.58 ±0.15	9.33 ±0.26	9.83 ±0.26	9.45 ±0.21

$Dp_{\bar{3}}$: A small low crowned molariform tooth similar in form to the remaining molars (L 8.2, AW 7.0, PW 7.3).

Lower molars: Molar tooth row curved progressively more medially in the sequence $M_{\bar{1}}$ to $M_{\bar{4}}$, while lophs of individual teeth show progressively more antero-mesial rotation in sequence $M_{\bar{1}}$ — $M_{\bar{4}}$. Lower molars increase in size from $M_{\bar{1}}$ — $M_{\bar{3}}$, then decrease to $M_{\bar{4}}$; they are similar in structure.

Anterior cinglum broad antero-posteriorly but does not extend across full width of tooth. Forelink originates labially just below apex of protolophid, descending to meet anterior cingulum labiad of midline. Slightly weaker midlink arises labially just below apex of hypolophid, descending median valley labiad of midline. No posterior cingulum. Anterior faces of lophs more heavily crenellated than posterior faces; condition being most marked in unworn juvenile (P16513).

Comments

Except for the greatly expanded frontal regions, the skull of *S. maddocki* superficially resembles that of *S. occidentalis*. Yet even without the frontal region, it is easily distinguished by its smaller molar teeth. The mandibles resemble those of *S. occidentalis*; although a cursory glance at the molars also suggests *S. gilli*. However closer examination of the distinctive $P_{\bar{3}}$, the symphysis, and/or the incisors immediately distinguishes it from these species. The functional aspects of the morphological differences will be discussed elsewhere (Wells & Murray in prep.).

All referred specimens are from the Victoria Fossil Cave complex, but *S. maddocki* recently has been recovered by one of us (Wells) from a submerged cave at Tantanoola in southeast South Australia.

Acknowledgments

We wish to thank Mr J. McNamara for his careful preparation of the specimens and Mr N. Pledge (South Australian Museum) for the loan of comparative material. This work was supported by grants from the Australian Research Grants Committee and the South Australian Government Department for the Environment.

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Registered for posting as a publication Category 'B'

Printed by Graphic Services Pty Ltd, 516-518 Grand Junction Road, Northfield, S.A. 5085